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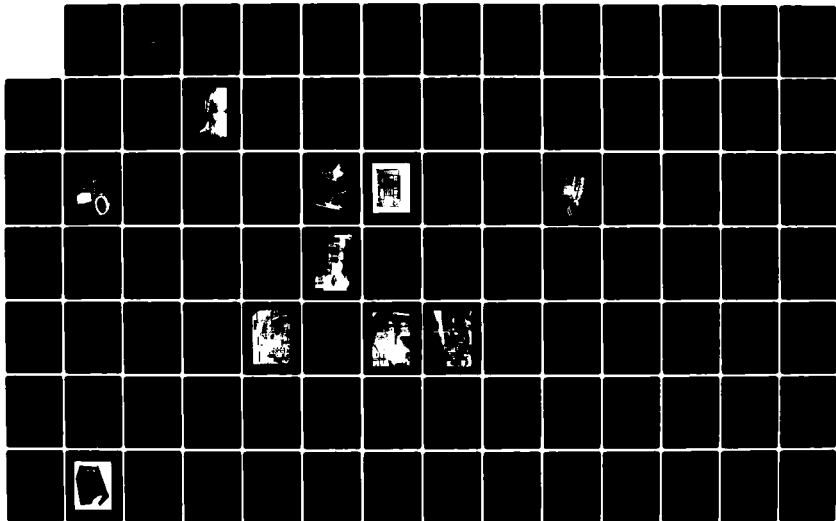
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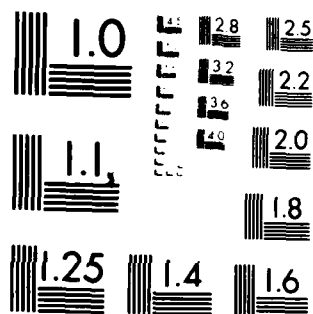
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FINAL TECHNICAL REPORT  
May 1983

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# FLIGHT EVALUATION OF A LINEAR OPTICAL DISPLACEMENT TRANSDUCER



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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NAC-TR-2329	2. GOVT ACCESSION NO. <b>AL32 638</b>	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle)  FLIGHT EVALUATION OF A LINEAR OPTICAL DISPLACEMENT TRANSDUCER	5. TYPE OF REPORT & PERIOD COVERED Final Report June 1982 - May 1983	
7. AUTHOR(s)  Ernest J. Solomon	6. PERFORMING ORG. REPORT NUMBER NR83H-20	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Rockwell International Corporation North American Aircraft Operations 4300 East Fifth Avenue, Columbus, OH 43216	8. CONTRACT OR GRANT NUMBER(s)  N00163-82-C-0232	
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Avionics Center Indianapolis, IN 46218	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Naval Air Systems Command AIR-332C Department of the Navy Washington, DC 20361	12. REPORT DATE May 1983	
	13. NUMBER OF PAGES	
	15. SECURITY CLASS. (of this report)  UNCLASSIFIED	
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE	
16. DISTRIBUTION STATEMENT (of this Report)  <div style="border: 1px solid black; padding: 5px; margin: 10px auto; width: fit-content;"> This document has been approved for public release and sale; its distribution is unlimited. </div>		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)  Computer Interface Unit Digital Fly-By-Light Linear Optical Displacement Transducer 8000 PSI (55 MPa) Lightweight Hydraulic System		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The flight demonstration and evaluation of the operation of the MIL-T-85289 Linear Optical Displacement Transducer (LODT) as an active sensing unit of the Advanced Flight Control Actuation System in a T-2C aircraft were successfully accomplished. The test installation contained a LODT as the rudder position feedback device, fiber optic link, computer interface unit, microcomputer, direct-drive rudder actuator, electronic drive unit, force transducers, and a localized 8000 PSI (55 MPa) hydraulic supply. The system met all laboratory and flight test objectives and demonstrated that the LODT represents a viable approach to EMI immunity in advanced aircraft control systems. ✓		

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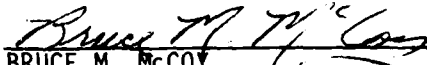
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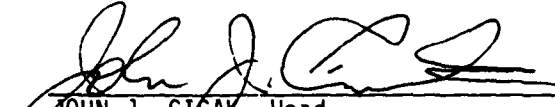
## FOREWORD


This report documents the flight evaluation of a prototype MIL-T-85289 Linear Optical Displacement Transducer (LODT) as a rudder actuator feedback control monitor. The program objective was to collect performance data of the flight response using the digital LODT in place of the analog Linear Variable Displacement Transducer (LVDT) in the Advanced Flight Control Actuation System (AFCAS) feedback loop. The test flights verified the LODT performance to be highly satisfactory using on-board measurement equipment and telemetry data relay. The laboratory tests showed the LODT to be very accurate with high sensitivity. The aircraft used was the T-2C trainer, Bureau No. 152382, bailed to Rockwell from the Naval Air Systems Command (NAVAIR), Washington, DC.

This flight evaluation was accomplished by Rockwell International (North American Aircraft Operations) for the Naval Avionics Center (NAC) under Contract No. N00163-82-C-0232. The principal investigator was Mr. L. L. Kohnhorst of Rockwell. Funding for this effort was provided by NAVAIR. The NAVAIR technology administrator for this project was Mr. A. Glista, AIR-332C. The program manager at NAC was Mr. John Cicak, Code 813. The NAC project engineers were Messrs. Peter Jones and Bruce McCoy, Code 813.

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# ABSTRACT

The flight demonstration and evaluation of the operation of the MIL-T-85289 Linear Optical Displacement Transducer (LODT) as an active sensing unit of the Advanced Flight Control Actuation System in a T-2C aircraft were successfully accomplished. The test installation contained a LODT as the rudder position feedback device, fiber optic link, computer interface unit, microcomputer, direct-drive rudder actuator, electronic drive unit, force transducers, and a localized 8000 PSI (55 MPa) hydraulic supply. The system met all laboratory and flight test objectives and demonstrated that the LODT represents a viable approach to EMI immunity in advanced aircraft control systems.

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## 1.0 INTRODUCTION

### 1.1 BACKGROUND INFORMATION

The MIL-T-85289 Linear Optical Displacement Transducer (LODT) was developed by the Hamilton Standard Division of United Technologies under contract to the Naval Avionics Center (Reference 1). The LODT was designed as an electrically passive means of accomplishing linear motion sensing in the rudder control system of a Rockwell International T-2C aircraft fitted with components comprising the Advanced Flight Control Actuation System (AFCAS). Rockwell served as developer of the AFCAS under contract to the Naval Air Development Center and provided NAC with recommendations for configuring the LODT, such as mechanical envelope and output code format, which would aid integration of the LODT into the AFCAS.

The LODT represents a unique application of the developing technology of airborne fiber optics to the field of flight control sensing. In order to gain confidence in the LODT's ability to function as a reliable component of a flight control system, it must undergo test while subjected to conditions of a flight operation which cannot be simulated in a laboratory environment.

The development of Advanced Flight Control Actuation Systems (AFCAS) for next generation aircraft has been a joint undertaking by the Navy and Rockwell International Corporation since 1972. The AFCAS concept developed by the Naval Air Development Center (NADC) is a direct drive, lightweight hydraulic, surface actuation system capable of being controlled with a direct digital command (References 2 through 7). This system was successfully flight tested in the T-2C aircraft in 1979 and was reported on in Reference 7.

The optical command link, developed and laboratory evaluated as part of the Navy's HOF CAS (Hydra-Optic Flight Control Actuation System, Reference 8) program was successfully flight tested and reported on in Reference 9.

The assets of the programs cited were utilized in the Flight Evaluation of a Linear Optical Displacement Transducer (LODT) program. Necessary modifications to integrate the LODT as an active sensing unit of the AFCAS installation in the T-2C aircraft, laboratory testing and subsequent flight evaluation are described in detail in this report.

## 1.2 OBJECTIVE

The objective of this program is to evaluate the operation of the MIL-T-85289 Linear Optical Displacement Transducer as an active sensing unit of the Advanced Flight Control Actuation System in a T-2C aircraft.

## 1.3 TECHNICAL APPROACH

The technical approach used in the evaluation of Linear Optical Displacement Transducer utilized the assets of the AFCAS and HOF CAS programs in conjunction with the LODT equipment, and to demonstrate through rigorous system laboratory tests the suitability of the LODT configured system for controlling the rudder of the T-2C aircraft.

The Electronic Drive Unit, and the Microcomputer Power Supply were used without change. Modifications to the microcomputer included the addition of a Gray-to-Binary code converter, differential line drivers and receivers, internal wiring and electrical connector to interface with the LODT Computer Interface Unit, and program changes to accommodate the LODT in the control loop and also provide an LODT analog output signal for instrumentation. Hardware for mounting the LODT to the actuator body was added to the AFCAS actuator. Two cable harnesses were added; one to provide interconnection between the CIU and the microcomputer, and the other to provide power to the CIU. Aircraft wiring changes consisted of paralleling the LVDT No. 1 output to both channels of the EDU.

The LODT evaluation criteria were selected to provide a broad range of system operation while maintaining compatibility with the T-2C dynamic performance requirements. Safety provisions, including failure mode evaluation, were based on T-2C flight safety requirements. Self-monitoring features in the microcomputer program cause the system to automatically revert to the Analog Back-Up (ABU) mode in the event that predetermined tolerances are exceeded in the digital equipment. The safety features also include a hydraulic by-pass valve on the direct drive actuator. This device allows the rudder to seek a trail position if the rudder control system failed. Flight testing on previous programs had established the aircraft can be safely landed with the rudder in the trail position. This feature establishes a third level of redundancy beyond the DFBL and ABU modes of control.

All major components needed to fly the LODT in the T-2C were assembled in the laboratory for system integration testing. System operation was verified in the laboratory prior to aircraft installation. Frequency response, step response, linearity, hysteresis and failure modes switching were performed simulating aircraft operation.

The test system was installed in the T-2C with instrumentation for the LODT and LVDT analog outputs as well as standard parameters such as airspeed, altitude, engine rpm, etc. Flight data were collected by photo recorder and telemetry systems.

Procedures were established for system checkout, ground demonstration, and flight testing. More than fifty (50) hours have been logged on the Digital Fly-By-Light system prior to the LODT test installation. Pilot observations and instrumentation data were used as a basis for evaluating the test LODT installation.

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## 2.0 T-2C AIRPLANE

### 2.1 GENERAL DESCRIPTION

The T-2C "Buckeye" is built by Rockwell International Corporation, North American Aircraft Operations-Columbus. The Buckeye is a two-place, subsonic trainer powered by twin turbojet engines. The aircraft is designed for both land and carrier based operations. Distinguishing features include wide-track tricycle landing gear, straight tapered wings, and low slung intake ducts, Figure 2-1.

The T-2C is equipped for cross-country flight, night flying and low altitude, high speed navigation exercises. Maximum level flight speed of the Buckeye is 465 knots (239 m/s) at 15,000 feet (4.6 km); the service ceiling is 45,000 feet (13.7 km). Takeoff and landing speeds are in the range of 95 to 110 knots (49 to 57 m/s). A typical takeoff gross weight is 13,000 pounds (5900 kg).

Dual power sources are provided for the electrical, hydraulic, and air-conditioning systems. The flight control system includes hydraulic full-powered ailerons, a boosted elevator, and an electric trim system; rudder operation is manual. The aileron and elevator actuators are part of mechanical linkage connecting the pilot's stick to the control surfaces. Thus, in the event of a hydraulic system malfunction, control of the aircraft can be accomplished manually.

### 2.2 HYDRAULIC SYSTEM

The T-2C has a 3000 psi (21 MPa), Type II (-65 to +275°F) (-54 to +135°C), single hydraulic system. Two pumps, one on each engine, provide power to operate the landing gear, speed brakes, arresting hook, aileron actuator, and elevator boost package. The pumps are constant pressure, variable delivery, axial piston designs. Each pump is capable of delivering 4.9 gpm (18.5 L/M) at 7800 rpm. Hydraulic fluid (MIL-H-5606) is supplied to the pumps by an air/oil type reservoir pressurized by engine bleed air. Fluid cleanliness is maintained by 5 micron absolute filters.

One pump can adequately handle all flow demands. However, if supply pressure should drop below 1800 psi (12 MPa), a priority valve is used to ensure operation of the aileron and elevator actuators. A cockpit controlled shutoff valve is installed in the aileron/elevator subsystem to permit simulating loss of power for training purposes. The landing gear and arresting hook can be lowered and locked by gravity, if desired. The wheel brakes have an independent hydraulic system.



Figure 2-1. T-2C "Buckeye" Trainer

### 2.3 ELECTRICAL SYSTEM

Electrical power is supplied by two 28 volt DC, 300 ampere starter-generators, one mounted on each engine. The generators are connected for parallel operation and power the primary bus. Output voltages are regulated for varying loads and engine speeds.

Two nickel-cadmium 24 volt rechargeable batteries are used for engine starting and emergency DC power. The batteries are normally connected in parallel, but are used in series for engine starting.

A portion of the 28 volt DC power is converted to 115 volt, 400 Hz AC power by two rotary inverters. Inverter No. 1 produces 500 volt-amperes for instruments; Inverter No. 2 supplies 1500 volt-amperes for avionics and serves as a backup source for instrument power.

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### 3.0 AFCAS DIRECT DIGITAL DRIVE, LODT FEEDBACK TEST INSTALLATION

#### 3.1 GENERAL DESCRIPTION

The fly-by-wire rudder control system incorporating a digital micro-computer generated PWM valve drive signal was originally installed in the T-2C aircraft during the AFCAS program (References 6 and 7). This system was modified under Contract N00163-82-C-0232 to test a Linear Optical Displacement Transducer as the feedback element for controlling the rudder of the T-2C aircraft while operating in the Digital Fly-By-Light (DFBL) mode. Principal components in the test installation are:

<ul style="list-style-type: none"><li>o Linear Optical Displacement Transducer (MIL-T-85289)</li><li>o Computer Interface Unit</li><li>o Fiber Optics Cable</li><li>o Gray-to-Binary Converter</li></ul>	Installed and tested per LODT program.
<ul style="list-style-type: none"><li>- EDU</li><li>- Localized Hydraulic Power Unit (8000 PSI)</li><li>- Force Transducers</li><li>- LVDT Position Transducer</li><li>- Microcomputer Assembly</li><li>- Microcomputer Power Supply</li></ul>	Previously installed & tested per Phase 5 & 6 of the AFCAS program.

Two modes of system operation are provided, the Digital Fly-By-Light (DFBL) mode and the Analog Back-Up (ABU) mode. In the DFBL mode, the microcomputer converts the pedal force command into a digital signal, sums it with the digital rudder position feedback signal from the LODT and generates a PWM error command signal. The PWM error signal is converted to an optical signal which is transmitted to the EDU via two fiber optic cables where it is restored to an electrical PWM signal, amplified and power converted into four separate coil currents within the actuator torque motor. In the ABU mode, the pedal force commands and rudder position feedback (now supplied by an LVDT) bypass the microcomputer and are connected directly to the EDU where they are summed, amplified and power converted into four separate coil currents within the actuator torque motor.

A functional block diagram of the major components is shown in Figure 3-1. The shaded areas indicate which components were added or changed for the Digital Fly-By-Light system incorporating the MIL-T-85289 Linear Optical Displacement Transducer.

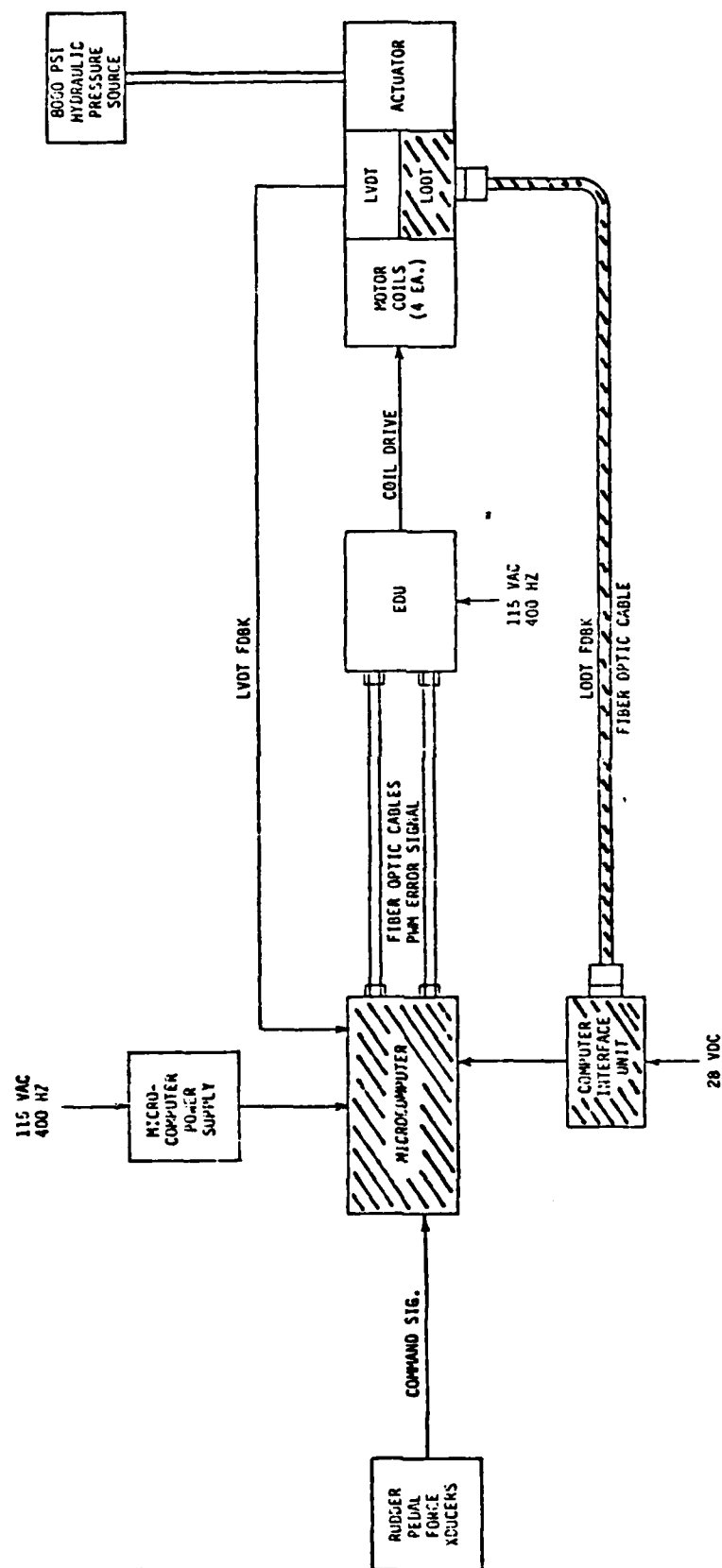


Figure 3-1. Digital Fly-By-Light, Linear Optical Displacement Transducer (LODT) Feedback, T-2C Test Installation - Simplified Block Diagram

### 3.2 SYSTEM DESCRIPTION

Figure 3-2 contains a functional block diagram that illustrates the DFBL and ABU modes of operation. A functional schematic of the system appears in Figure 3-3.

The DFBL mode is selected by momentarily holding the cockpit DFBL ENGAGE switch to ON, energizing the DFBL control relays and resulting in the following:

- o The pedal command and LODT feedback signals are connected to the microcomputer inputs. EDU pedal command and LVDT feedback signal inputs are grounded.
- o The microcomputer PWM error command is connected to the EDU via the fiber optic control links.

If the microcomputer senses the system is functioning properly, a power ground is continuously supplied to the DFBL ENGAGE switch holding coil by the microcomputer and the system remains in the DFBL mode.

The ABU mode may be selected by manually placing the DFBL ENGAGE switch to OFF. The ABU mode is automatically selected when the microcomputer senses abnormal system operation in the DFBL mode.

Switching to the ABU mode results in the following:

- o The fiber optic error command link output in the EDU is disabled and the pedal command and LVDT feedback transducer outputs are connected directly to the EDU where they are summed and power amplified to drive the four coils in the torque motor of the actuator direct drive valve.

The various system components are discussed in the following paragraphs.

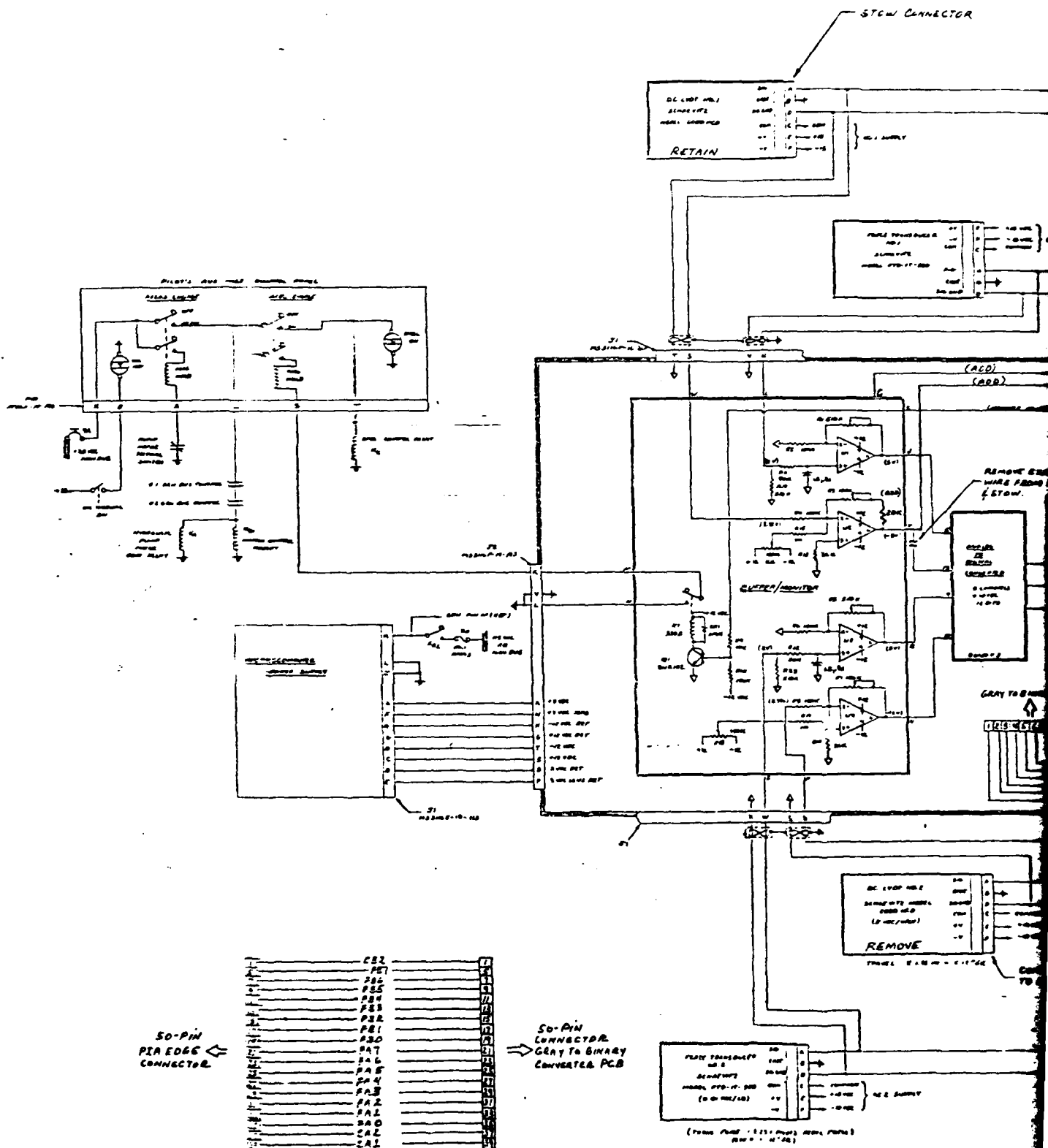
#### 3.2.1 Actuator Position Transducers

##### LODT (MIL-T-85289(AS))

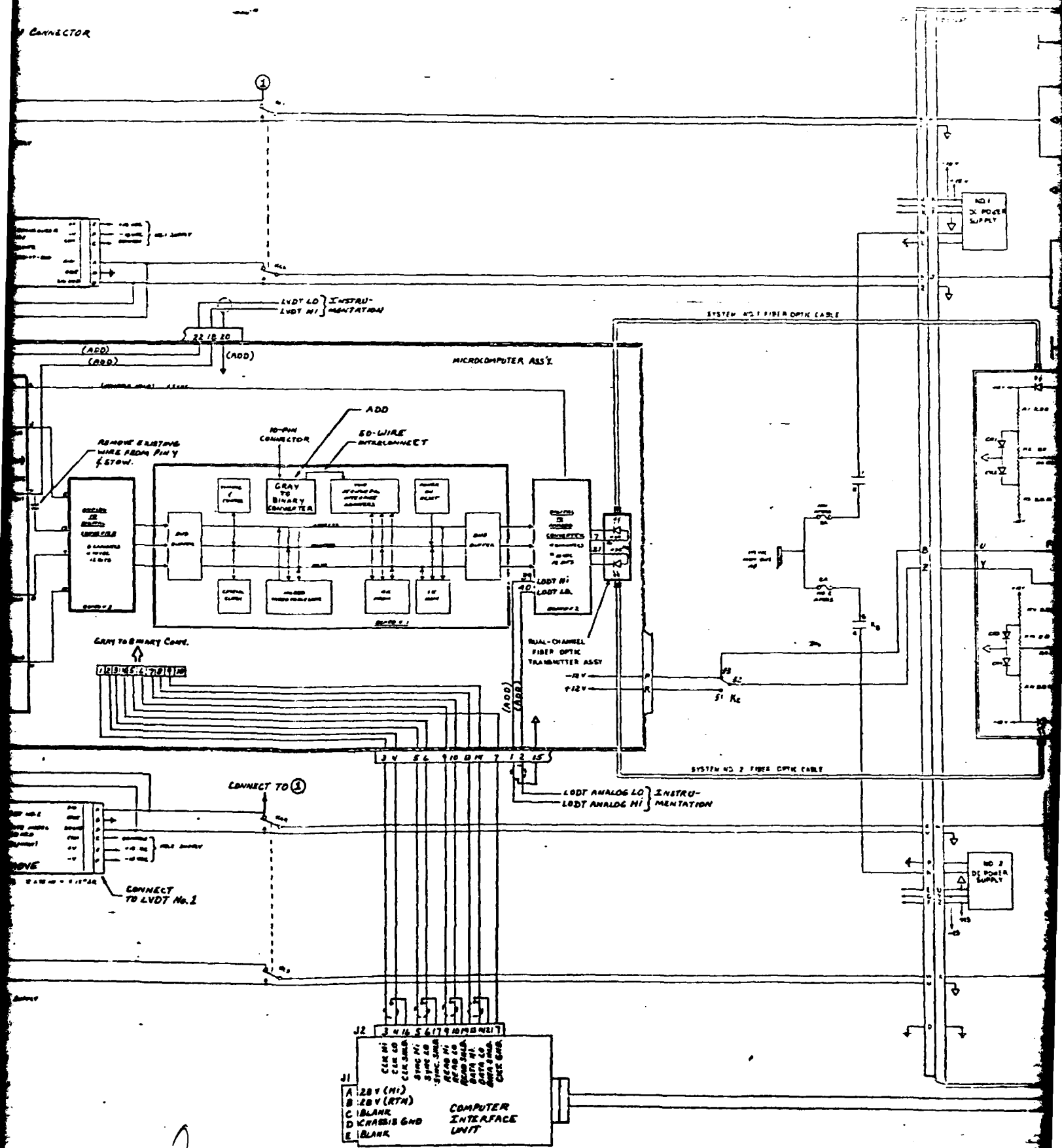
The Linear Optical Displacement Transducer (LODT) provides the rudder actuator feedback signal in the Digital Fly-By-Light (DFBL) mode. The LODT MIL-T-85289(AS) equipment consists of the Displacement Transducer, Fiber Optic Link and Computer Interface Unit as shown in Figure 3-4. A cut-away view of the transducer is shown in Figure 3-5. Mounting of the transducer on the rudder actuator is shown in Figure 3-9.

Absolute linear position over the + 1.75 inches (+ 4.45 Cm) of travel is provided by means of a 12-bit Gray code using a fiber optic face plate made up of a glass substrate with a chrome encoder mask. The 12-bit data provides measurement resolution of approximately 0.0008 inches (0.02 mm). A digital-to-analog converted LODT signal is provided, for instrumentation, in both the DFBL and ABU operational modes.

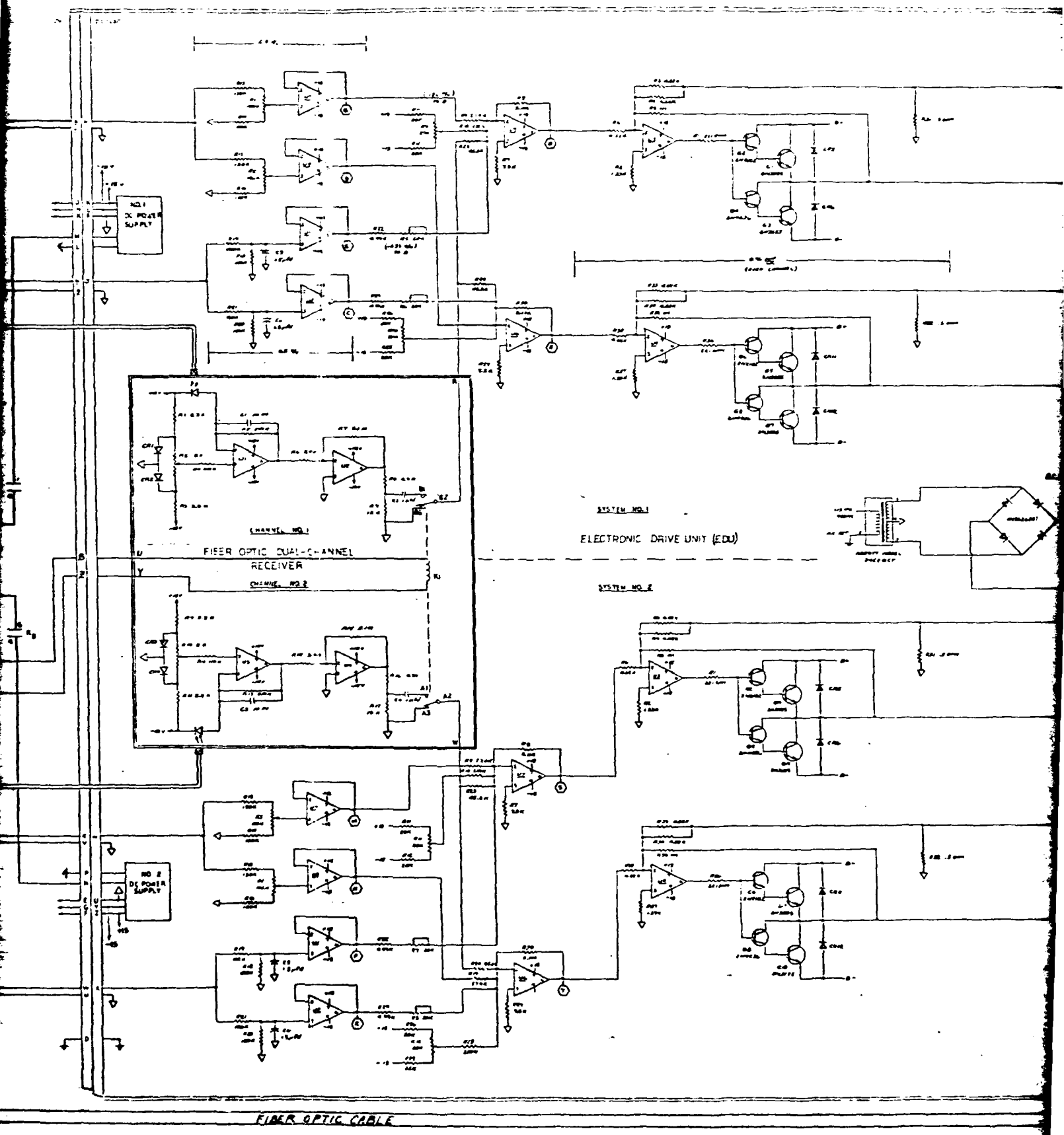




CONNECTOR



1 2



SYSTEM NO. 1  
ELECTRONIC DRIVE UNIT (EDU)

SYSTEM NO. 2

FIBER OPTIC CABLE



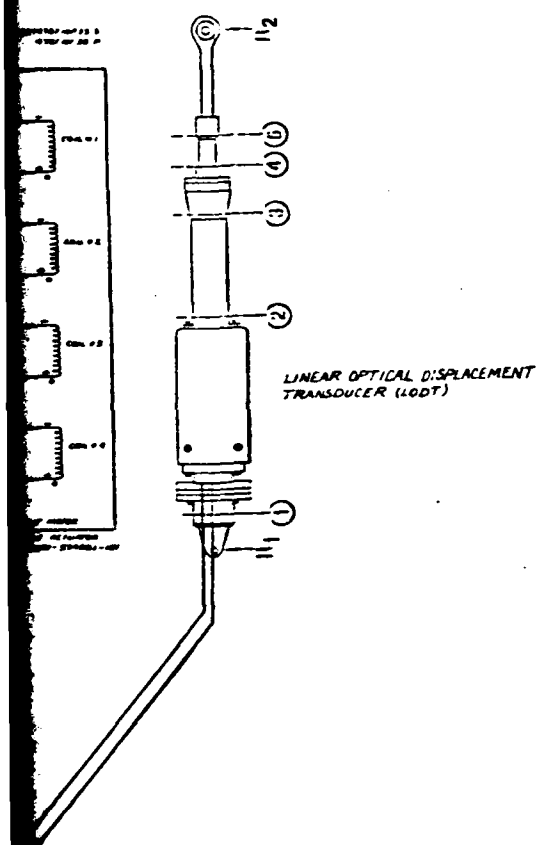


Figure 3-3. Digital Fly-By-Light System, T-2C Rudder Control, Functional Schematic

DATE	10/10/77	REVISION	1
COLUMBIA AIRCRAFT COMPANY North American Division Burbank, CA 91506			
DIGITAL FLY-BY-LIGHT SYSTEM, T-2C AIRPLANE - LRC - INSTALL			
PROJECT NUMBER	89372	INFORMATION PRINT	

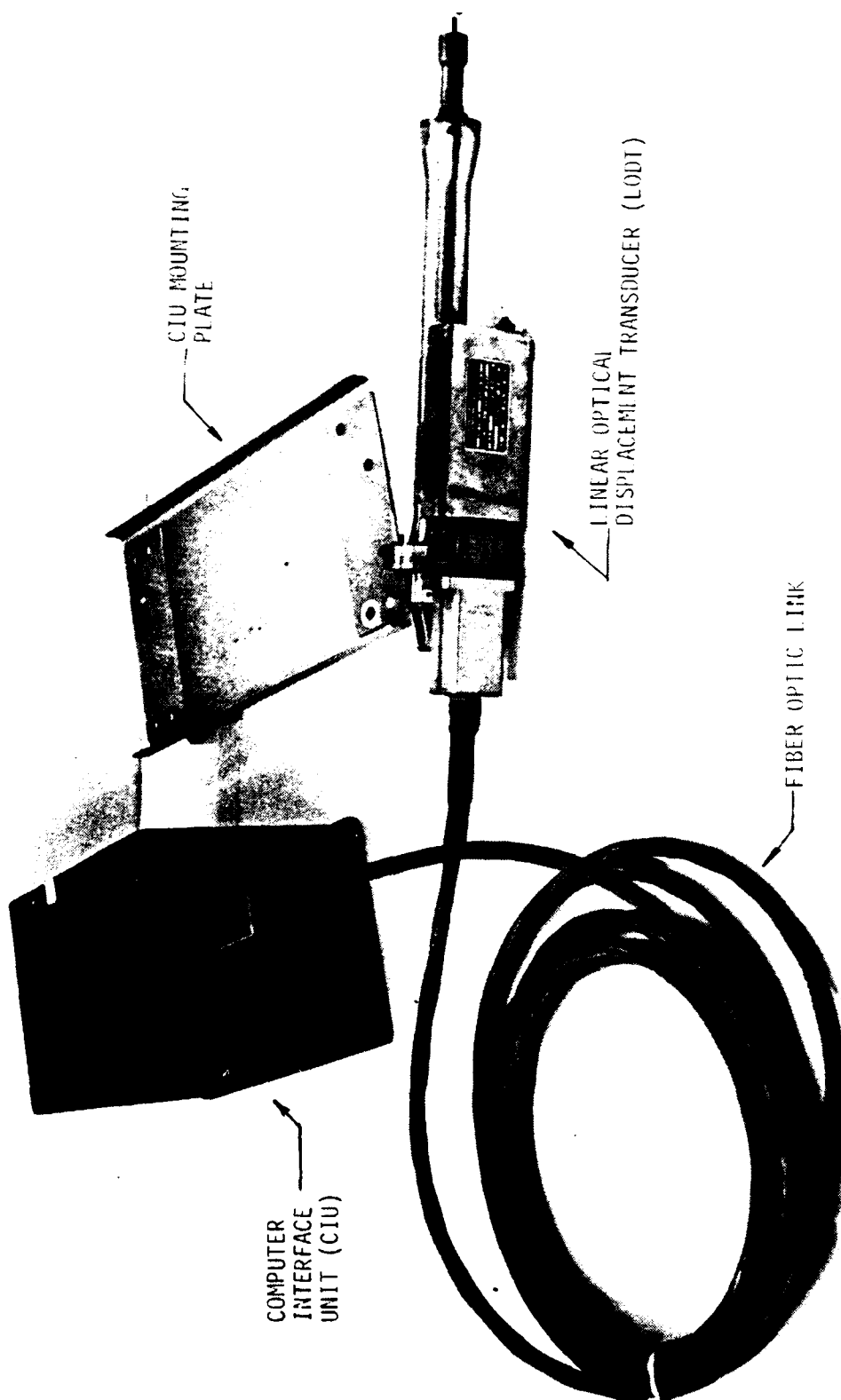


Figure 3-4. Linear Optical Displacement Transducer Equipments, MIL-T-85289(AS)

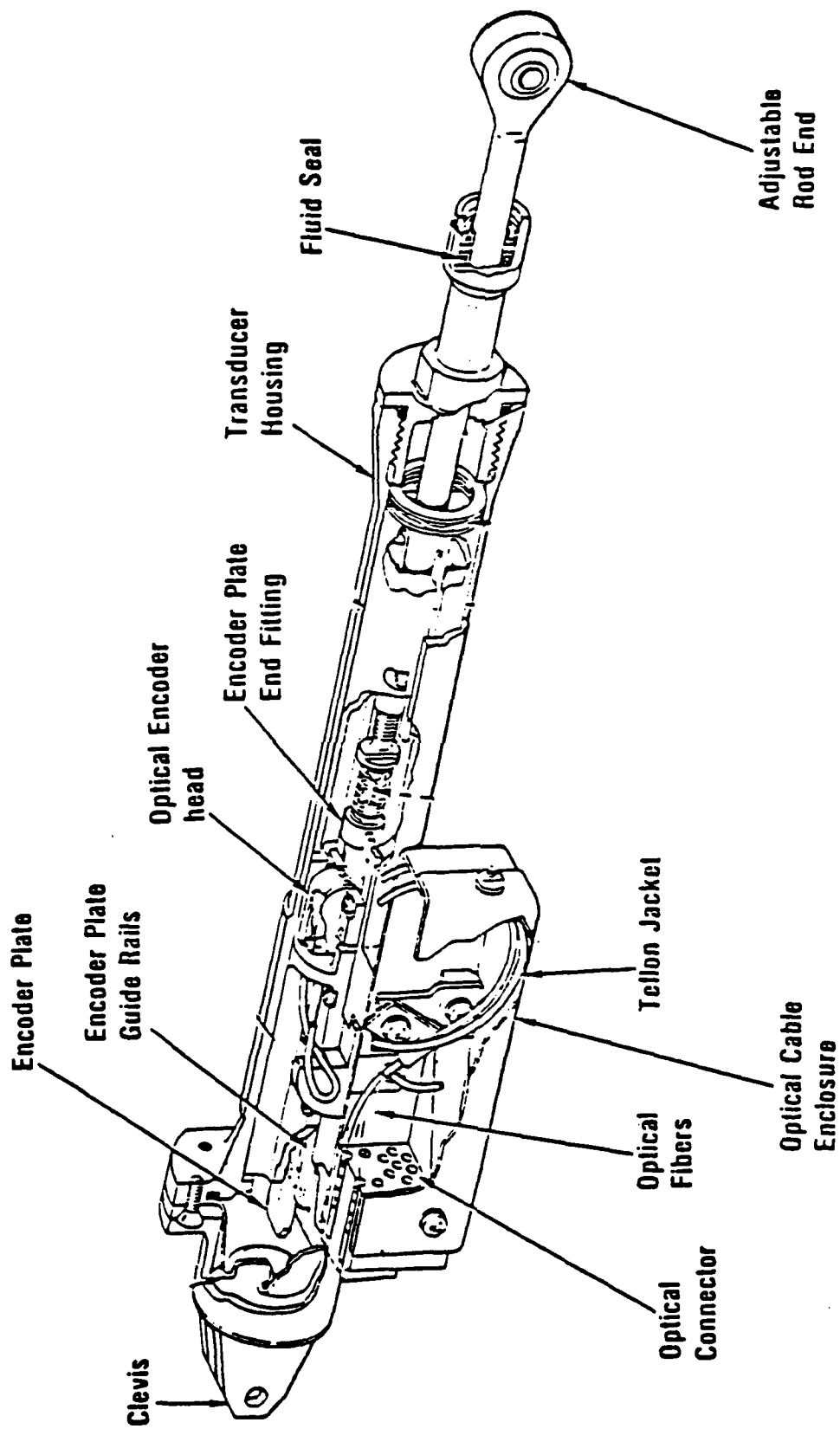


Figure 3-5. Linear Optical Displacement Transducer, Cut-Away View

### LVDT

A Schaevitz Model 2000 HCD DC Linear Variable Differential Transformer (LVDT) provides the rudder actuator feedback signal in the ABU mode. In the DFBL mode, the LVDT is used for monitoring the validity of the LODT feedback signal.

LVDT excitation is provided by the EDU + 15 VDC power supply. The LVDT scale factor is 5.0 VDC/in (1.97 VDC/Cm). The actuator linear position travel, + 1.75 in. (+ 4.45 Cm) max., is converted through a bell crank and push rod to an angular rudder travel of + 12° max. The LVDT is shown mounted on the rudder actuator in Figure 3-9.

#### 3.2.2 LODT Fiber Optic Link

The LODT Fiber Optic Link consists of four bundles of seven fibers, each packaged in a single strengthened cable. A 20-pin Hughes type C22 fiber optic connector is terminated identically on each end. Dust covers are supplied to maintain cleanliness of the fiber optic pin during storage. The overall cable diameter is 3/8" (9.525 mm) with a 3.7 inch (9.4 Cm) minimum bend radius. The strain relief of the connector and the Kevlar strength members of the cable provide an overall pull strength in excess of 80 lbs. (356 N).

Two of the seven fiber bundles are used to transmit the light emitted by the LED's to the transducer. Six fibers in each of the other two bundles are used to return the encoded signals from the transducer to the CIU. Each of the 28 fibers is a low loss, 100 micron core, 140 micron clad, graded index, communication grade, glass-on-glass fiber with a single buffer. The fiber optic link is shown in Figure 3-4 interconnected between the CIU and LODT.

#### 3.2.3 Dual Channel PWM Fiber Optic Links

The dual channel fiber optic links are used to transmit Pulse Width Modulated (PWM) rudder error signals from the microcomputer to the Electronic Drive Unit. The unipolar optical PWM signals are received in the EDU and restored to bipolar electrical PWM signals to drive the actuator control valve. Commercially available fiber optic components were used for both the transmitters and receivers.

#### 3.2.4 Computer Interface Unit (CIU)

The Computer Interface Unit contains the active electro-optic devices, and the control and signal processing electronics for interfacing with the Flight Control Computer. The CIU interrogates the transducer upon receipt of a read command from the Flight Control Computer. Two Light Emitting Diodes (LED's) are pulsed upon receipt of the read command. The transducer is interrogated and the encoded signal is received via twelve photodiodes. The diodes and a transimpedance amplifier are packaged in a custom hybrid that provides less susceptibility to EMI and provides a low noise level output. The data is received in parallel by the twelve photodiodes. The CIU and its aircraft mounting plate are shown in Figure 3-4.

### 3.2.5 Electronic Drive Unit

The EDU in Figure 3-6 contains the electronics for sensor signal conditioning, signal summation, and power amplification to current drive the torque motor. The EDU was designed and fabricated by North American Aircraft Operations. It consists of two independent channels, each subdivided into dual valve driver circuits. A functional schematic of the EDU electronics is included in Figure 3-3. Each of the four power amplifiers employs current feedback with a highly reliable "Darlington" power transistor configuration, utilizing redundant power supplies. The circuitry is designed so that in the event an output stage fails "hard-over", the voltage applied to a motor coil will not exceed its rated value. This limiting feature permits a sub-unit failure to be compensated or nullified by another sub-unit. Closed loop tests showed that operation of the redundant sub-units provided a high immunity to component failures as reported in Reference 4, NR75H-1, Control by Wire Modular Actuator Tests (AFCAS).

### 3.2.6 Pedal Force Transducers

Two force transducers, Schaevitz Model FTD-IT-500 (Figure 3-7), are used to convert pedal forces into DC signals. Excitation is provided by the EDU + 15 VDC power supplies. The force transducers are connected to the pedals through a cable/sector assembly having a mechanical advantage of 2.28 (pedal force x 2.28 = transducer force). The transducers have a maximum capacity of 500 lbs. (2.2 kN), a spring rate of approximately 8000 lb/in (1.4 MN/m), and a design scale factor of 0.01 v/lb (.002 v/N).

### 3.2.7 Microcomputer Assembly

The microcomputer assembly is housed in an enclosed unit, and consists of the following subassemblies:

<u>Part No.</u>	<u>Nomenclature</u>
M68MM01A	Motorola Mono-Board Microcomputer Module
M68MM05A	Analog-To-Digital (A/D) Converter Module
M68MM05C	Digital-To-Analog (D/A) Converter Module
M68MMCC05	Card Cage & Mother Board Assembly
EO H383246-11	Signal Conditioning Board
EO H384415	Gray Code Converter

The mono-board microcomputer module is shown in Figure 3-8, and is a complete computer-on-a-board having all the processing and control required for a microcomputer-based system. It incorporates the MC 6800 MPU, 1 K of Random Access Memory (RAM), provisions for 4 K of Programmable Read Only Memory (PROM), timing and control, buffers, an Asynchronous Interface Adapter (ACIA) and two Peripheral Interface Adapters (PIA).

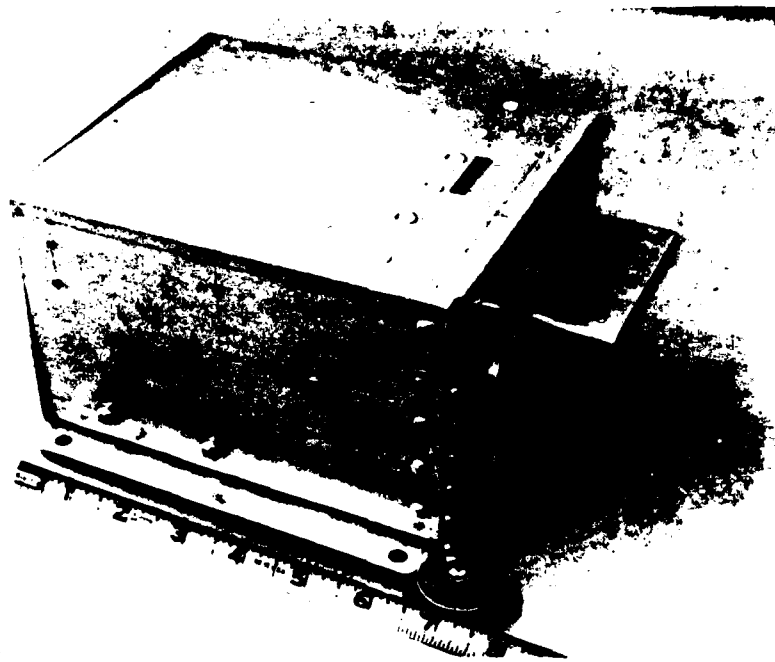


Figure 3-6. Electronic Drive Unit

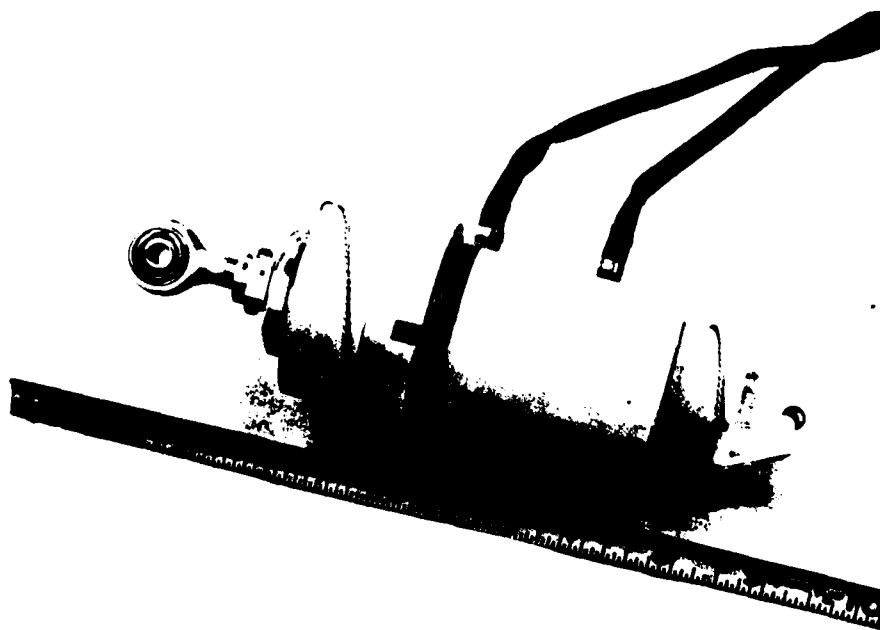


Figure 3-7. Force Transducer

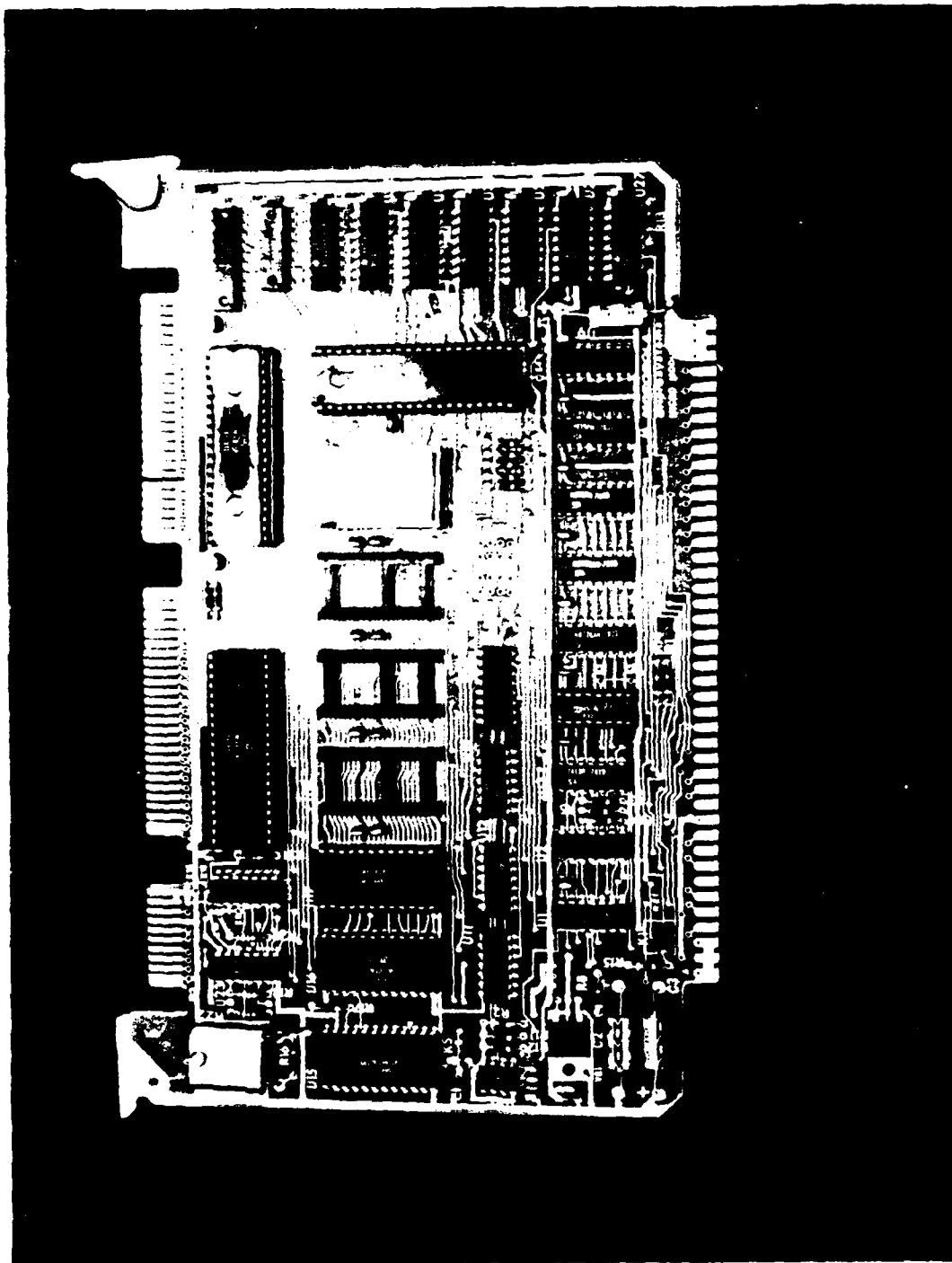


Figure 3-8. Motorola M68MM01A Microcomputer Monoboard Assembly

The A/D converter module consists of eight channels of A/D conversion of which four are utilized. The D/A converter module consists of four channels of D/A conversion.

The signal conditioning board contains four channels of sensor signal conditioning and a relay driver that interfaces the microcomputer monitor output with the system control logic.

Additional information on the microcomputer assembly is contained in Appendix A.

The Gray Code Converter board enables the computer to interface with the optical transducer's Computer Interface Unit (CIU). The Gray Code Converter's buffers change the CIU differential signals to standard TTL level signals. The serial Gray code data from the CIU is then converted to straight binary by the use of an exclusive OR and shift registers. The shift registers in the Gray Code Converter have two functions. The first function is to enable exclusive OR-ing of the previous bit with the present bit to generate the straight binary. The second function is serial to parallel conversion with temporary storage. The data to be loaded into the computer is stored in the shift registers until the computer is ready to read the data. When the data has been shifted into the registers, a flag in the PIA is set which informs the computer that data is ready for loading. After loading the data, the computer resets the shift registers so that another conversion can be started. All conversions start after the computer sends the CIU a read pulse.

### 3.2.8 Microcomputer Power Supply

A separate power supply, Motorola P/N M68MMPS1, converts single-phase, 115 VAC, 400 Hz to + 5 VDC, and + 12 VDC to power the microcomputer assembly.

### 3.2.9 AFCAS Actuator

The fly-by-wire AFCAS rudder actuator, P/N 8691-524001-101, is directly driven by a permanent magnet force motor having four independent coils for redundancy. The force motor armature is mechanically coupled to a spool/sleeve flow control valve which commands actuator piston rate. Piston feedback is provided by a DC LVDT and LODT mounted externally on opposite sides of the actuator housing. A hydraulic bypass valve was added to automatically interconnect the two cylinder chambers in the event hydraulic power were lost. The T-2C rudder has a travel of + 25°. For safety reasons, rudder travel was reduced to + 12° in the test installation by limiting actuator stroke. This permits the pilot to land safely with a "hard-over" rudder, opposite engine out, and three knot cross-wind.

Actuator constants are listed below:

Operating Pressure	8000 psi (55 MPa)
Piston Stroke (Total)	3.5 In. (8.9 cm)
Cylinder Bore	0.926 In. (2.3 cm)
Rod Diameter	0.748 In. (1.9 cm)
Piston Effective Area	0.234 In. <sup>2</sup> (1.5 cm <sup>2</sup> )
Force Output (Max.)	1870 Lb. (8.3 kN)
Piston Velocity (Rated)	5.5 In/Sec. (14 cm/s)
Actuator Length (Extended)	18.375 In. (46.7 cm)

The actuator assembly is shown mounted on a laboratory test fixture in Figure 3-9.

### 3.2.10 Hydraulic System

The hydraulic system remained unchanged from Phase V of the AFCAS test program, described in Reference 6. Changes incorporated in the basic T-2C hydraulic system for the Phase V test program were:

- o Addition of an electric motor driven 8000 psi (55 MPa) variable delivery pump.
- o Addition of an 8000 psi (55 MPa) control-by-wire rudder actuator and bypass valve.
- o Addition of a suction line from the reservoir to the 8000 psi (55 MPa) pump, pressure line from the pump to the rudder actuator, and actuator return line.
- o Addition of pump case drain return and shaft seal overboard line.
- o Relief valve installed in the 8000 psi (55 MPa) system.
- o Heat exchanger installed in the 8000 psi (55 MPa) pump case drain line.

The original and modified hydraulic systems are compared schematically in Figure 3-10.

The modified system is shown schematically in Figure 3-11; 8000 psi (55 MPa) components are listed in Table 3-1. The 3000 psi (21 MPa) and 8000 psi (55 MPa) systems shared a common reservoir and common return lines. All major components, except for the rudder actuator, were located in the fuselage compartment above the engines.

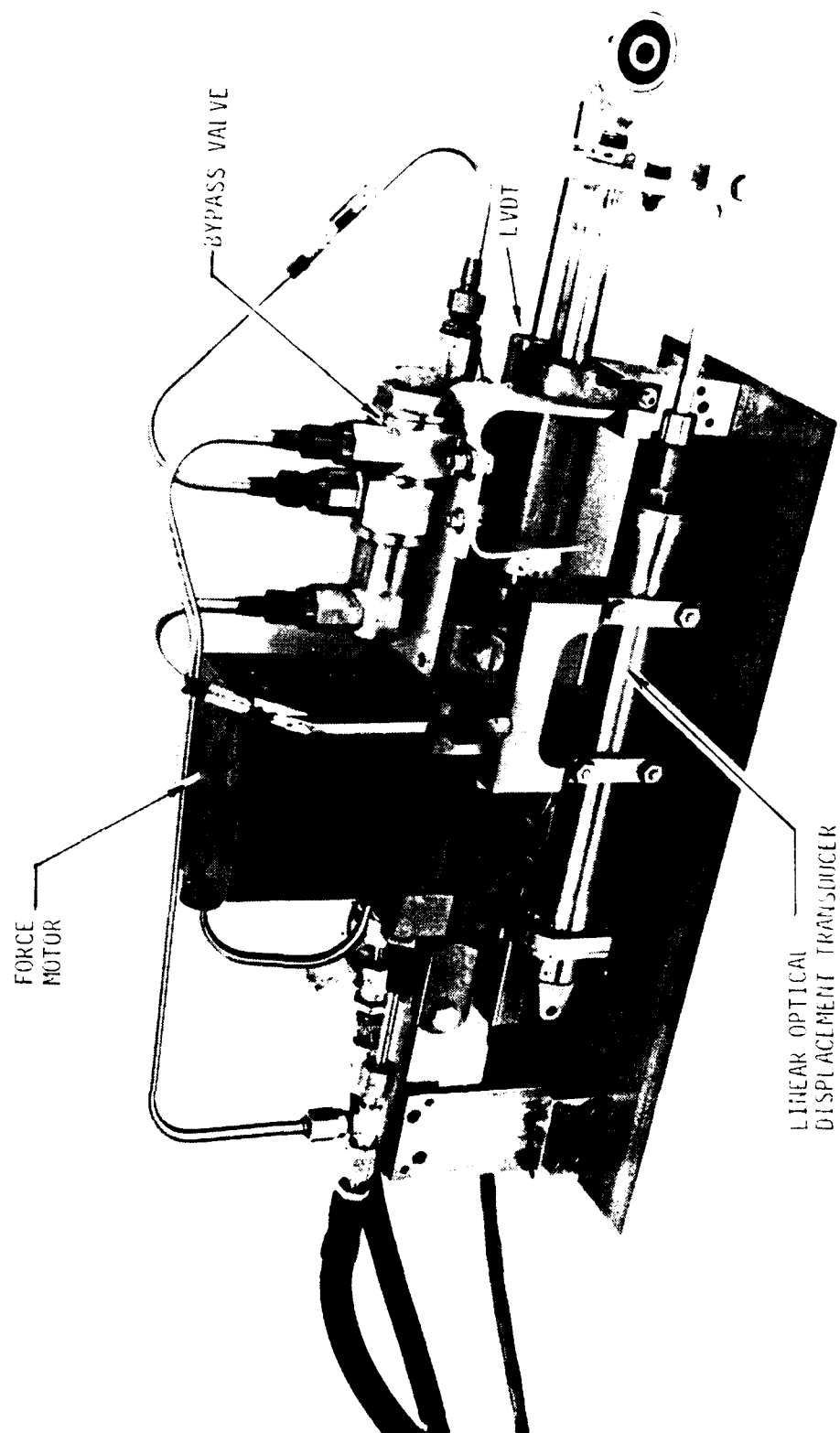
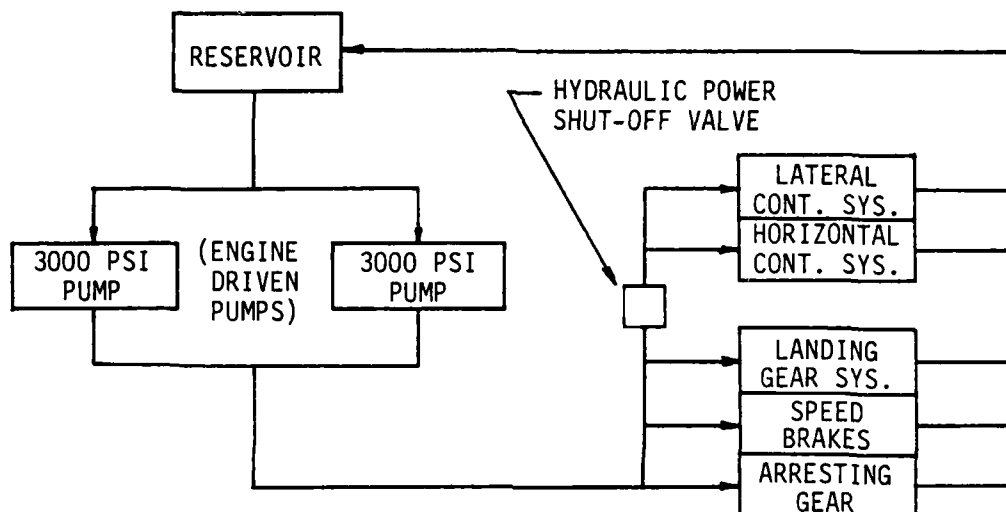
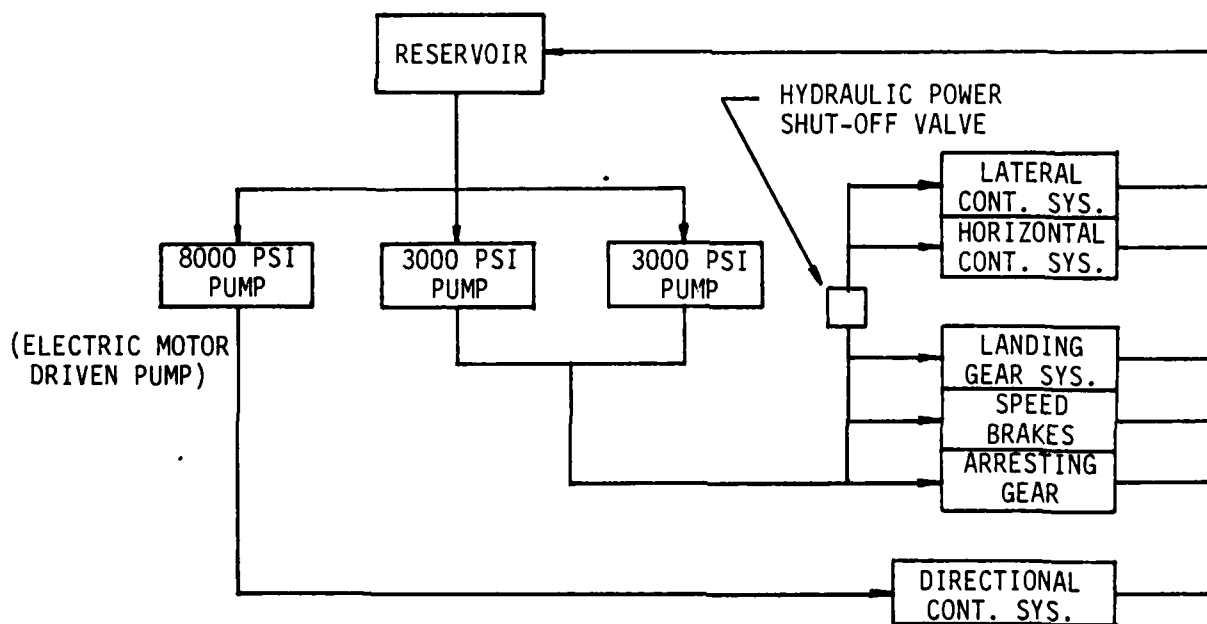


Figure 3-9. AFCAS Rudder Actuator/LDDT Assembly



ORIGINAL 3000 PSI SYSTEM



MODIFIED HYDRAULIC SYSTEM

Figure 3-10. Original and Modified Hydraulic Systems

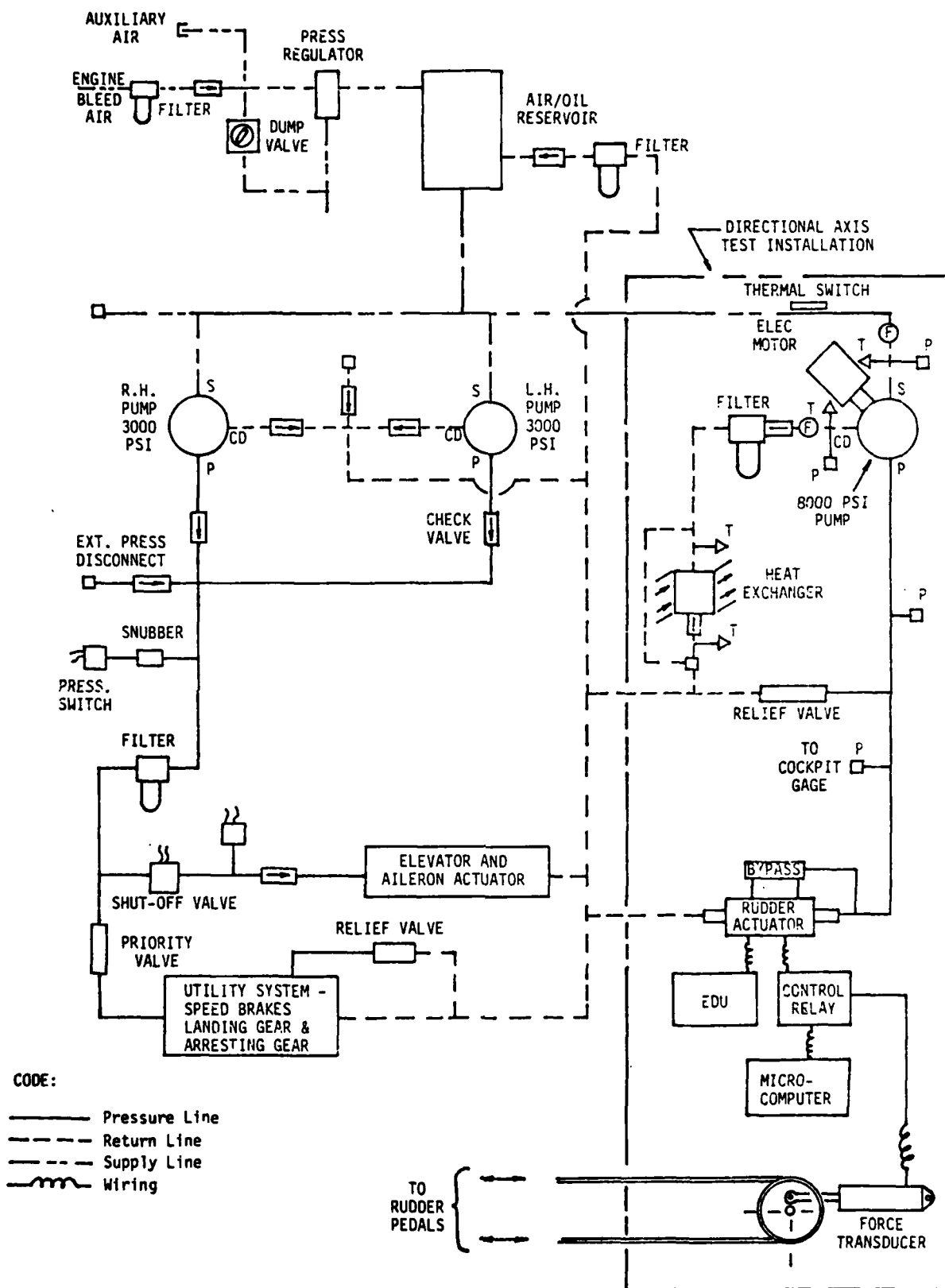


Figure 3-11. Schematic Diagram of Modified Hydraulic System

TABLE 3-1  
LIST OF 8000 PSI (55 MPa) COMPONENTS

<u>PART NO.</u>	<u>DESCRIPTION</u>	<u>MANUFACTURER</u>
66059	Motor/Pump Unit	Aerospace Division of Abex Corporation  Aerospace Electrical Division of Westinghouse Electric Corporation
8691-524001-101	Rudder Actuator Assembly	North American Aircraft Operations, Columbus Plant, Rockwell International Corporation
8691-524001-051	Bypass Valve	North American Aircraft Operations, Columbus Plant, Rockwell International Corporation
1180A	Hydraulic Relief Valve	PneuDraulics, Inc.
R44598-6-0310	Hose	Resistoflex Corporation
21-6-9	Tubing	Trent Tube Division of Colt Industries
Dynatube <sup>®</sup> Series	Fittings	Resistoflex Corporation
MIL-H-83282	Fluid	Royal Lubricants Co.

<sup>®</sup> Dynatube, a Resistoflex development, is patented in the United States and foreign countries.

### 3.3 SOFTWARE DESCRIPTION

#### 3.3.1 Function

Software was developed to enable the microcomputer to perform three basic functions; a command/feedback control function, a control monitor function, and a digital-to-analog conversion of the LODT feedback signal for instrumentation recording.

The command/feedback control function sums the pilot command and rudder position signals to produce an output signal proportional to the difference to drive the actuator.

The control monitor function measures the level of error between the pedal command and the rudder actuator position feedback, and if a preset level is exceeded for a given period of time, the engage command will be removed. Actuator control will then revert to the ABU mode. A continuous check is also made on the LODT and LVDT transducer input A/D conversion hardware by comparing the two digital feedback signals with each other and in a similar manner comparing the digital pedal signals. Any differences exceeding preset levels for a given period of time will result in automatic switching of system control to the ABU mode.

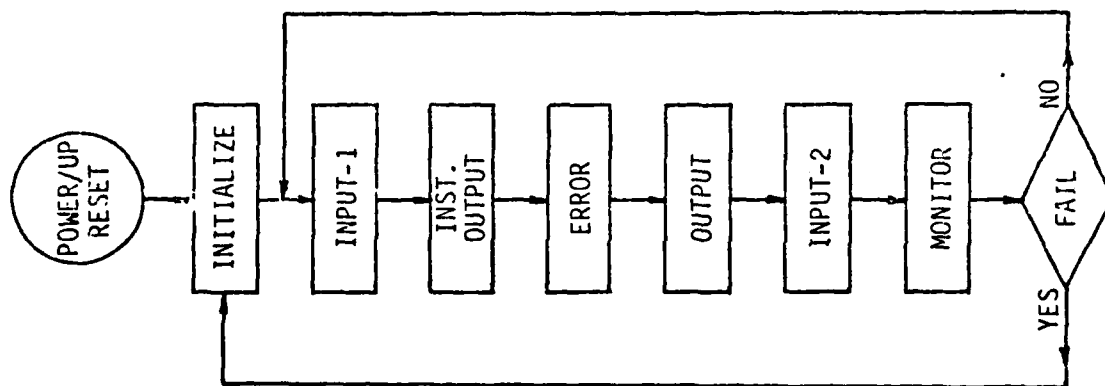
#### 3.3.2 Program Modules

The DFBL Microcomputer Program Flow Chart, Figure 3-12, illustrates the modular nature of the software and the sequence in which the modules function. The program modules were designed, coded, and initially checked as individual entities prior to being integrated.

Following is a brief description of the program modules:

Initialize - The Initialize module sets the D/A Converter (DAC) channel 4 to provide + 5 VDC to hold in relay K1 (ref. Figure 3-3). The K1 relay, in turn, holds the DFBL Engage switch in the engage position. The Initialize module also clears the Gray to Binary Converter and programs the PIA for the necessary I/O. All timing counters are also set to ensure that the Monitor function does not immediately turn off the DFBL Engage switch.

Input 1 - The Input 1 module, as the first in the repetitive loop, is used to start the PWM output signals. This is done by setting both DAC-1 and DAC-2 at + 10 VDC. It then reads the command or LODT depending on the status of a memory location. If the memory location is set, the module reads the LODT, otherwise it reads the command. The program operates at 500 Hz, which corresponds to reading the command or feedback at 250 Hz. A/D conversion of the command is controlled by this module and so is the start of a read pulse to signal the CIU for data. Data which is to be outputted to instrumentation is also done during execution of this module.



PROGRAM CHANGES

INITIALIZE

- INITIALIZE PIA
- INITIALIZE GRAY CODE CONVERTER

INPUT-1

- LOAD COMMAND
- LOAD POSITION
- RESETS GRAY CODE CONVERTER
- START LODT READ

INST. OUTPUT

- OUTPUT LODT SIGNAL

MONITOR

- CLEAR LODT READ

Figure 3-12. Digital Fly-By-Light Microcomputer Program Flow Chart

Command 1 Limit - Inputs are scaled so that full scale,  $+120^\circ$  of rudder is  $+5$  VDC, which is one-half of full range for the A/D channels. Since the force transducer that provides CMD1 is not mechanically or electrically limited to  $+5$  VDC, a software limit is provided to set CMD1 at either  $+5$  VDC, as appropriate, when that value is exceeded. Output of the A/D converter is a 12-bit word, proportional to the voltage.

Error - The Error module performs a double precision subtract of CMD1 from POST and sets computer gain through a series of shifts. It then determines polarity of the error and transfers to the appropriate output module.

Output - The Output module sets countdown timers that establish the duration of the plus and minus portions of the PWM output signal. It switches DAC-1 and DAC-2 to  $-10$  VDC when the "positive" counters have timed-out. When the "minus" counters time-out, it transfers control to the Input 2 module.

Input 2 - The Input 2 module controls the conversion of CMD2 and POS2 and provides limits on CMD2 in the same manner as Input 1. CMD2 and POS2 are for use in the Monitor functions.

Monitor - The Monitor module compares the redundant pilot command and rudder position input signals. If a difference in either of  $1.50^\circ$  is detected for a period of 0.128 seconds, the program is set to deenergize the DFBL holding relay (K1 in Figure 3-3) and reverts control of the system into the ABU mode. The monitor also checks the magnitude of the error signal. If it exceeds  $1.50^\circ$  for 2 seconds, the DFBL holding relay is deenergized, and control of the system again reverts to the ABU mode. As long as the monitor does not detect an error, it transfers control back to the Input 1 module. The LODT read pulse which was started in the Input 1 module is also reset at the start of this module.

### 3.3.3 Flight Test Program Software

Support software, trade name "Microbug ROM" was purchased with the microcomputer equipment and enabled communications with the microcomputer via a Teletype Corp. Model 33TU teletype keyboard/printer reader/punch unit. An RS-232-T0-TTY adapter unit provided the interface through the ACIA, between the microcomputer and the teletype.

The communication consisted of entering both program, monitoring microcomputer operation, and dumping of programs onto paper tape for storage.

After the software modules were operating satisfactorily they were then merged to become an operational program. After checking the operational program with the microcomputer integrated into the rudder system (in the laboratory), the program was then loaded into a PROM. The PROM was installed in the microcomputer and the operational program verified. All subsequent final system response testing and calibration for the flight configuration was performed with this PROM installed in the microcomputer.

I

A listing of the flight program software is contained in Appendix B. The program was designed to function at a rate of 500 Hz, and occupies 610 bytes of the available 4096 bytes of PROM and 19 bytes of the 1024 bytes of "scratch pad" RAM. The PROM map is also contained in Appendix B.

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## 4.0 LABORATORY TESTS

### 4.1 TEST OBJECTIVES

Laboratory tests were conducted on the integrated Linear Optical Displacement Transducer (LODT)/AFCAS system. The objective of the tests was to verify the performance of the Digital Fly-By-Light rudder control system with LODT feedback by comparing system performance data with that obtained using conventional LVDT feedback. Testing included failure modes as well as operational modes and monitoring of instrumentation parameters to ensure a high level of confidence in system compatibility prior to aircraft installation.

### 4.2 TECHNICAL APPROACH

The actual aircraft hardware was used whenever possible in the lab test set-up to permit testing and evaluation of the flight hardware and to eliminate potential problems during subsequent installation and operation in the aircraft.

Included in the lab test set-up were the rudder LVDT and LODT feedback transducers, rudder actuator, EDU, microcomputer and associated power supply, Computer Interface Unit (CIU), digital display unit, fiber optic cable, and the control panel switches and control relay used in the aircraft. A laboratory hydraulic pump was utilized for all tests requiring hydraulic flow.

### 4.3 INTEGRATION TESTS AND RESULTS

#### 4.3.1 Lab Set-Up

A lab wire harness, configured to simulate the aircraft wiring, was used. A terminal strip/interconnection board provided control, test points, and the interface between the wire harness, system components, and lab test equipment. A pictorial of the lab set-up is shown in Figure 4-1, and the associated block diagram is depicted in Figure 4-2.

The hydraulic supply used for the laboratory testing utilized a variable displacement, axial piston, 4000 psi (27.5 MPa) pump. An accumulator of approximately 50 in<sup>3</sup> (820 cm<sup>3</sup>) was used in the supply line to minimize supply pressure transients.

#### 4.3.2 LODT, CIU and Fiber Optic Cable Bench Tests

The LODT was mounted on a laboratory test fixture with the rod end attached to a precision positioning device. Appropriate electrical and fiber optic cable interconnections were made between the units under test. The availability of a Digital Display Unit (DDU) provided a convenient method of performing end-to-end operational checks on the LODT, CIU and Fiber Optic Cable. The DDU provided readouts of LODT displacement

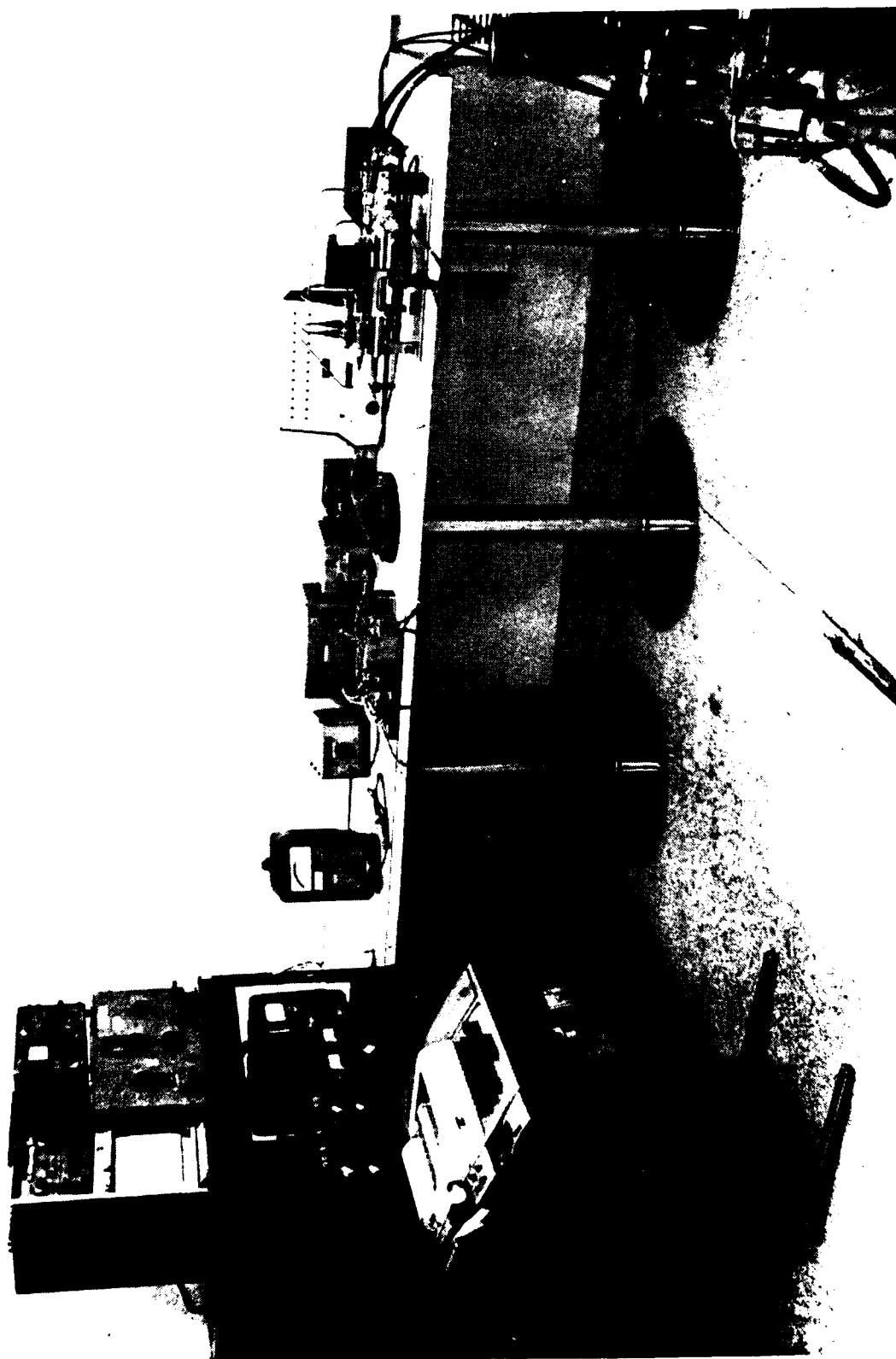


Figure 4-1. Linear Optical Displacement Transducer (LODT)/AFSAS System, Laboratory Test Set-Up

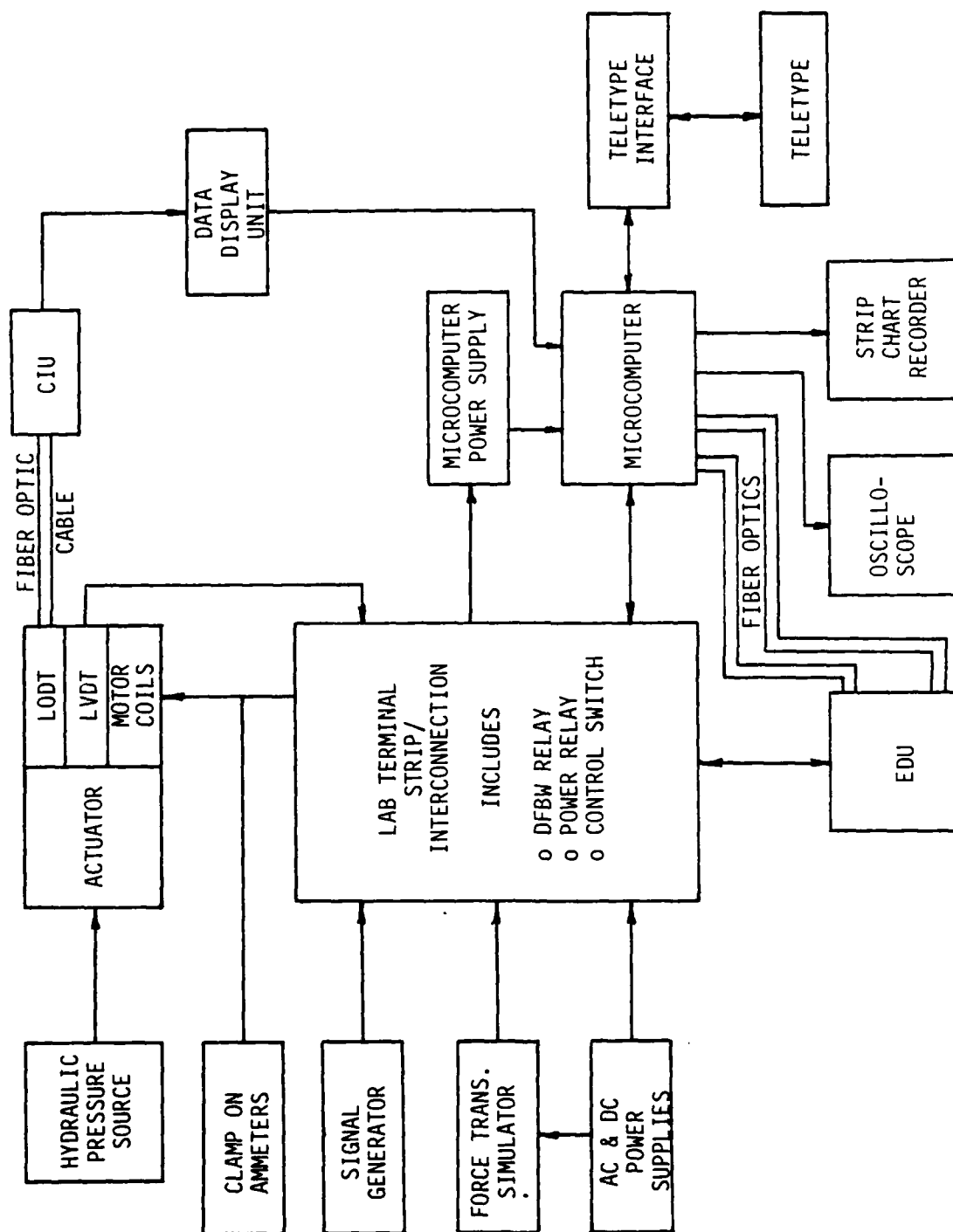


Figure 4-2. LODT/AFCAS System Lab Test Set Up, Block Diagram

in inches with corresponding Gray code and binary LED readouts. Required outputs from the equipment were verified prior to interfacing with the AFCAS components.

#### 4.3.3 Digital Program and System Operation

The digital program used in Phase VI of the AFCAS program (Reference 7) was modified to accommodate the digital feedback signals from the LODT and its associated CIU. During this development stage, the modified digital program was loaded into the AFCAS microcomputer random access memory (RAM) via the teletype and punched paper tape. This provided the capability to make program changes, as necessary, to obtain proper system operation and desired LODT instrumentation output. Failure mode sensing and signal amplitude features of the software program were also monitored. After verification, the software program was stored in a PROM and installed in the microcomputer for system laboratory testing, and subsequent installation in the T-2C aircraft.

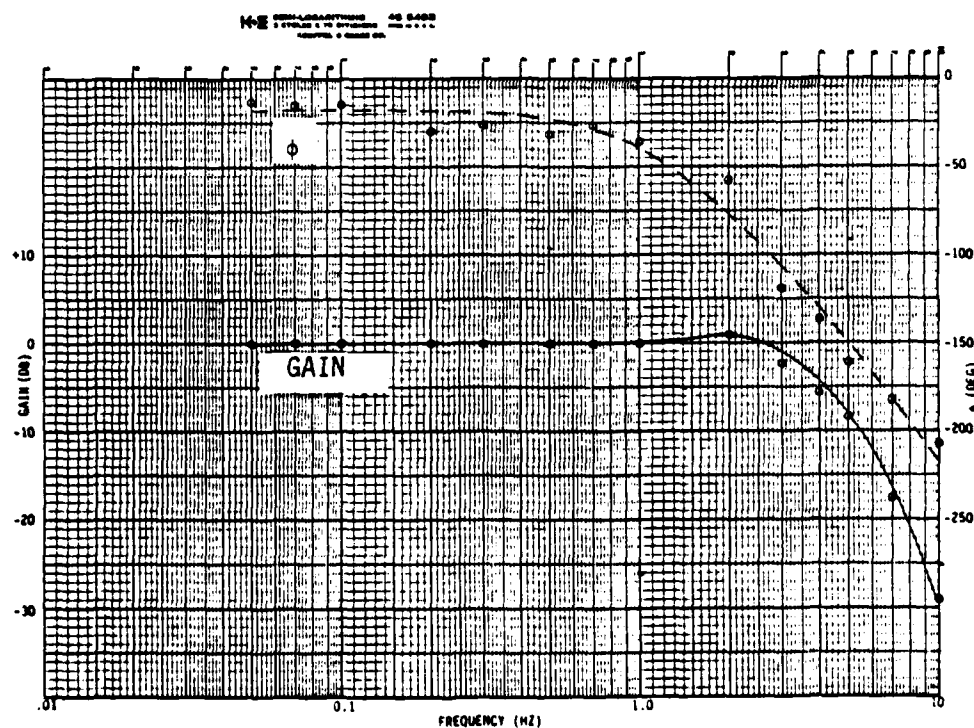
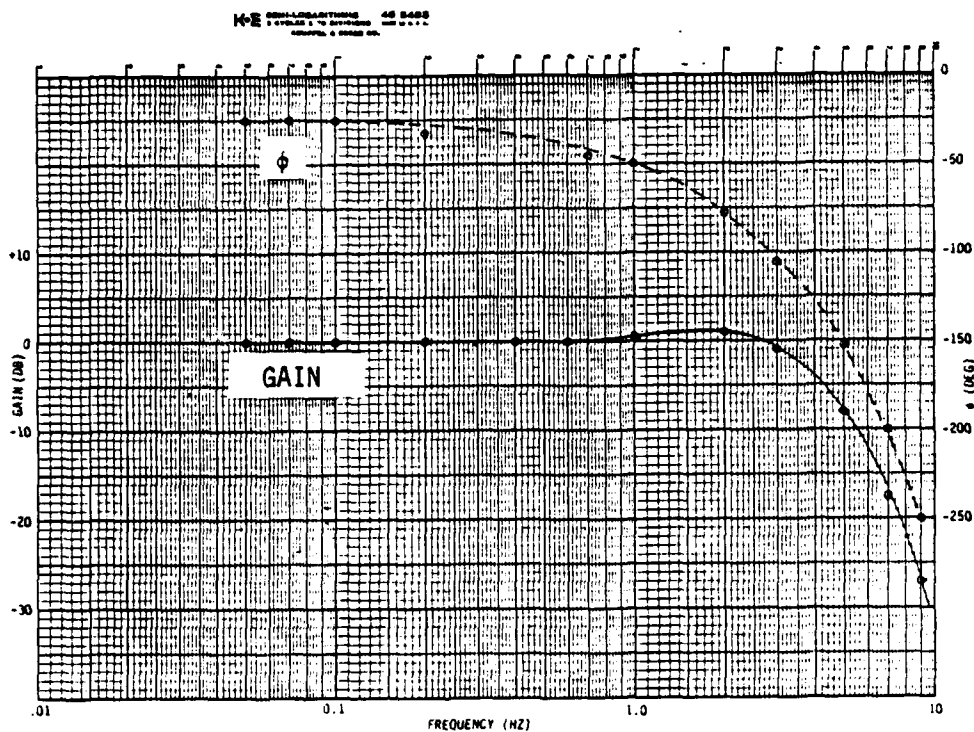
#### 4.3.4 System Response Tests

System response tests were performed in both the Digital Fly-By-Light (DFBL) and Analog Back-Up (ABU) operational modes. Drive signals were injected into the pedal command input at an amplitude representing approximately  $\pm 0.2$  inches (5.1 mm) of actuator travel. The drive signal and either the LODT or LVDT feedback signal, as required, were recorded on a strip chart recorder to provide frequency, gain and phase shift data. System performance comparisons are presented showing the DFBL mode system response with LODT feedback and previous DFBW data with LVDT feedback taken from the Reference 8 report.

4.3.4.1 DFBL Frequency Response - Figure 4-3 shows the Digital Fly-By-Wire mode frequency response with LVDT feedback reported in Reference 8. System bandpass is 3.5 Hz (3 db point) with a gain margin of 12 db and phase margin of 55 degrees. Figure 4-4 shows the Digital Fly-By-Light mode frequency response with LODT feedback. Essentially identical results were obtained, verifying that system frequency response is unaltered when the LODT is used as the feedback element.

4.3.4.2 ABU Frequency Response - The Analog Back-Up mode frequency response from Reference 8 data is shown in Figure 4-5. System bandpass is 0.7 Hz with a gain margin of 27 db and a phase margin of 110 degrees. Since the LODT is not used to close the loop in the ABU mode, this data was rerun only to verify that using one LVDT for both EDU channels had little or no effect on system response or scale factor. Figure 4-6 ABU mode frequency response shows a bandpass of 1.0 Hz with a gain margin of 32 db and a phase margin of 100 degrees which compares very closely to Reference 8 data.

4.3.4.3 DFBL and ABU Mode Step Responses - The DFBL mode step response is shown in Figure 4-7. Both the LODT digital-to-analog converted signal and the LVDT signal were recorded for comparison purposes. It is seen that LODT output is identical to the LVDT output and therefore should not



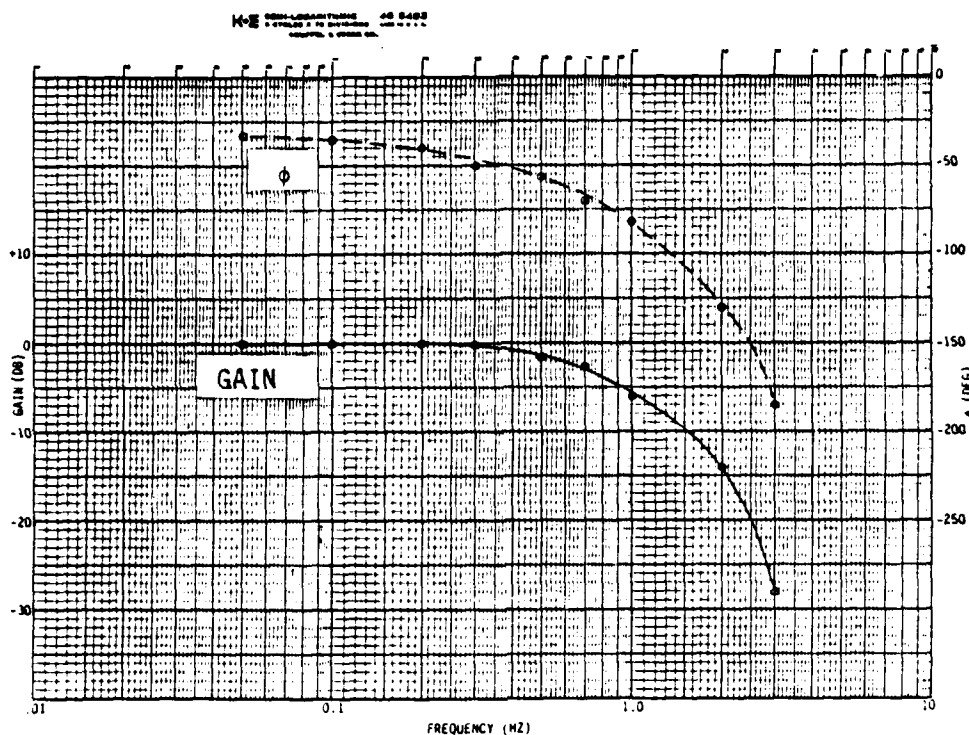


Figure 4-5. System Frequency Response, Analog Back-Up Mode, LVDT Feedback (Reference 7 Data)

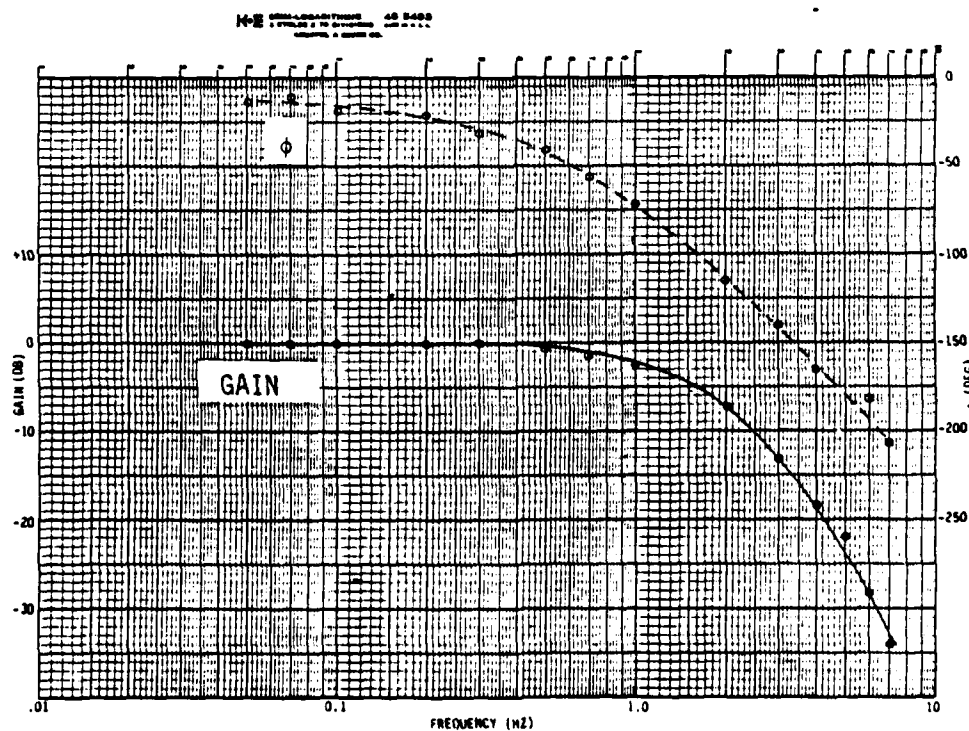


Figure 4-6. System Frequency Response, Analog Back-Up Mode LVDT Feedback (LODT Program Data)

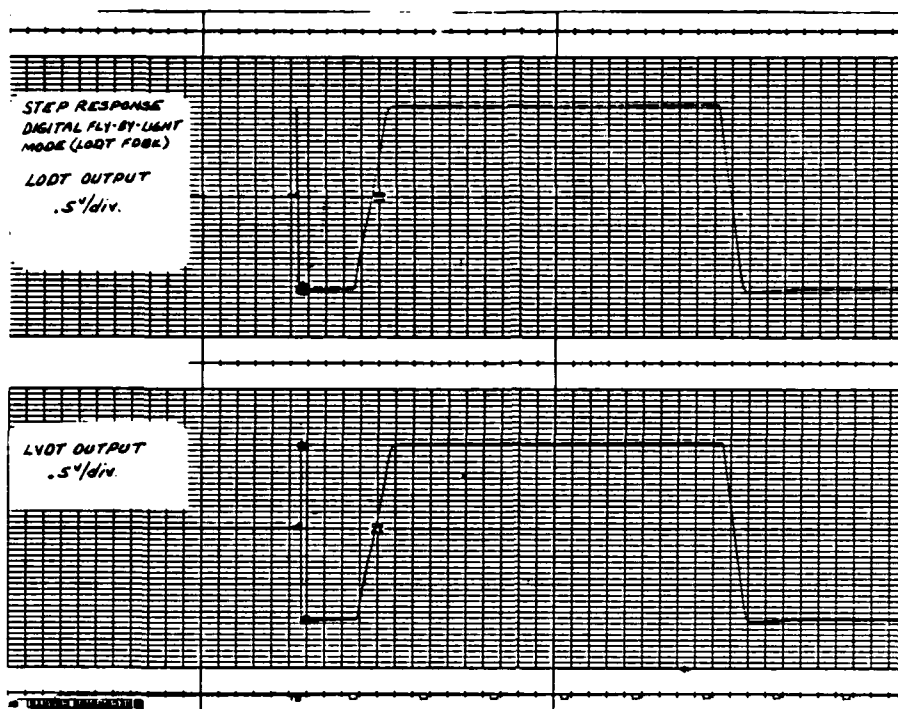


Figure 4-7. Step Response, Digital Fly-By-Light Mode

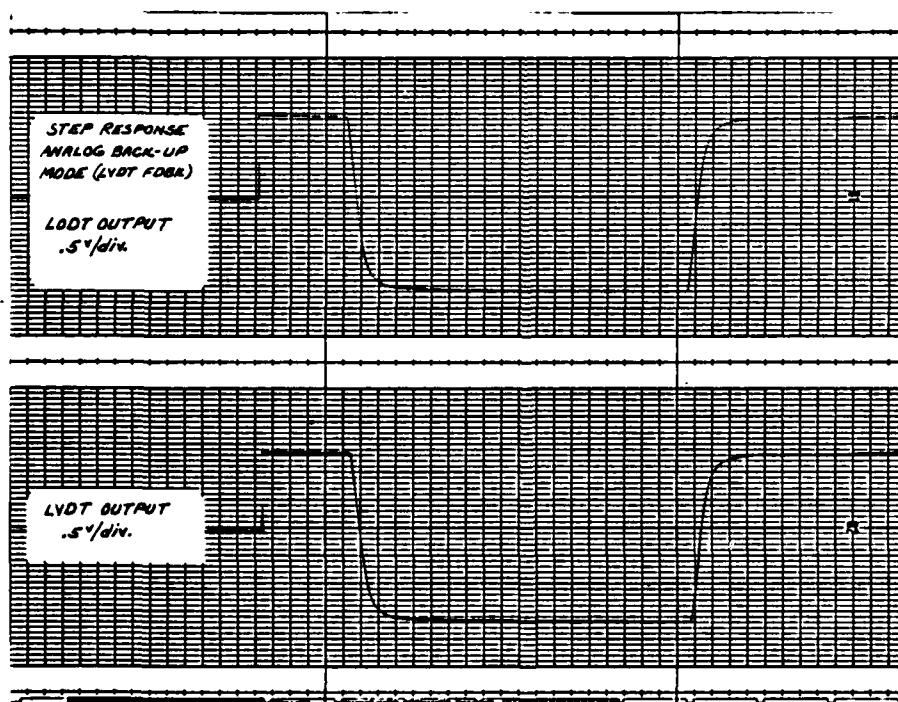


Figure 4-8. Step Response, Analog Back-Up Mode

degrade system operation. The maximum slewing rate calculated from Figure 4-7 DFBL mode data is 40°/sec and exhibits stable control loop operation with very little overshoot and satisfactory damping. The ABU mode step response shown in Figure 4-8 exhibits a maximum slew rate of 52°/sec and a damping of at least 0.7 with no overshoot. The 40°/sec DFBL slew rate is more than adequate, but is slower than the ABU slew rate. The reason is that the Pulse Width Modulation in the DFBL mode is intentionally limited to 88% to maintain capacitive coupling of the error command signal.

4.3.4.4 Linearity - A low frequency triangular wave (0.2 Hz) was used to check system linearity in both the DFBL mode with LODT feedback and the ABU mode with LVDT feedback. Measured system linearity in the DFBL mode was 0.2% of full scale taken from strip chart recording shown in Figure 4-9. Measured system linearity in the ABU mode was 1.25% of full scale taken from strip chart recording shown in Figure 4-10.

4.3.4.5 Failure Mode Tests - Simulated failures were induced while the system was fully operational in the DFBL mode with LODT feedback to demonstrate the ability of the system to sense the failure and revert to normal operation in the Analog Back-Up mode with LVDT feedback.

Simulated loss of LODT fiber optic cable - Figure 4-11 shows the LODT output in the upper channel and the LVDT output in the lower channel with the system operating in the DFBL mode at the outset of the test. The procedure consisted of inserting a steady state rudder pedal command and with the strip chart recorder running at 50 mm/sec, removing the fiber optic cable connector from the CIU, and recording the sequence of switching from the DFBL mode to the Analog Back Up (ABU) mode. At the instant the connector is removed, the LODT output goes to -10 VDC (the analog equivalent of all digital 0's coming from the LODT), while the LVDT output continues to monitor true rudder position. In approximately 0.1 second the ABU mode is automatically switched in and the rudder returns to its original position. The time from the initial failure to the return of the rudder to its original position in the ABU mode occurred in 0.62 seconds. The transient would be noticeable, but insignificant to the pilot.

Simulated loss of CIU power - Figure 4-12 shows the continuous time history of automatic switching from the DFBL mode to the ABU mode during an induced loss of power to the Computer Interface Unit (CIU). As would be expected, loss of power to the CIU produces results very similar to the failure mode described in paragraph 4.3.4.5.1. The failure is sensed and automatically switched from the DFBL mode to the ABU Mode in approximately 0.1 seconds. Complete recovery and control of the rudder to its commanded position occurs in approximately 0.65 seconds. The effect in-flight would be a slight transient and virtually no loss in control continuity.

4.3.4.6 Null Currents - Coil (4 ea) currents in the torque motor were measured with the rudder pedal command and the rudder position inputs grounded. The measured values for the DFBL and ABU modes of operation are shown in Table 4-1.

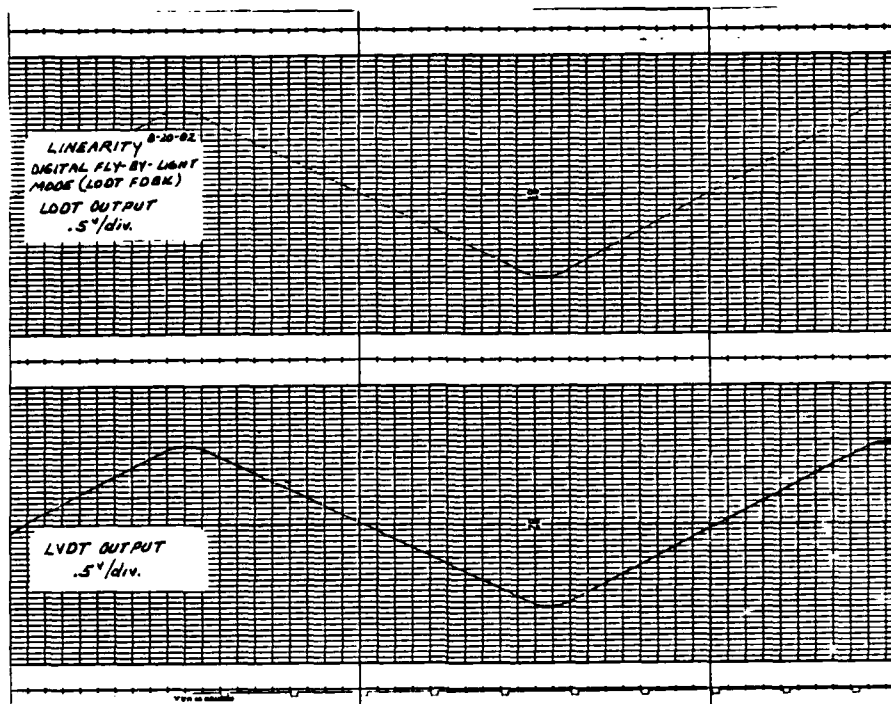


Figure 4-9. Control Loop Linearity, Digital Fly-By-Light Mode With LQDT Feedback

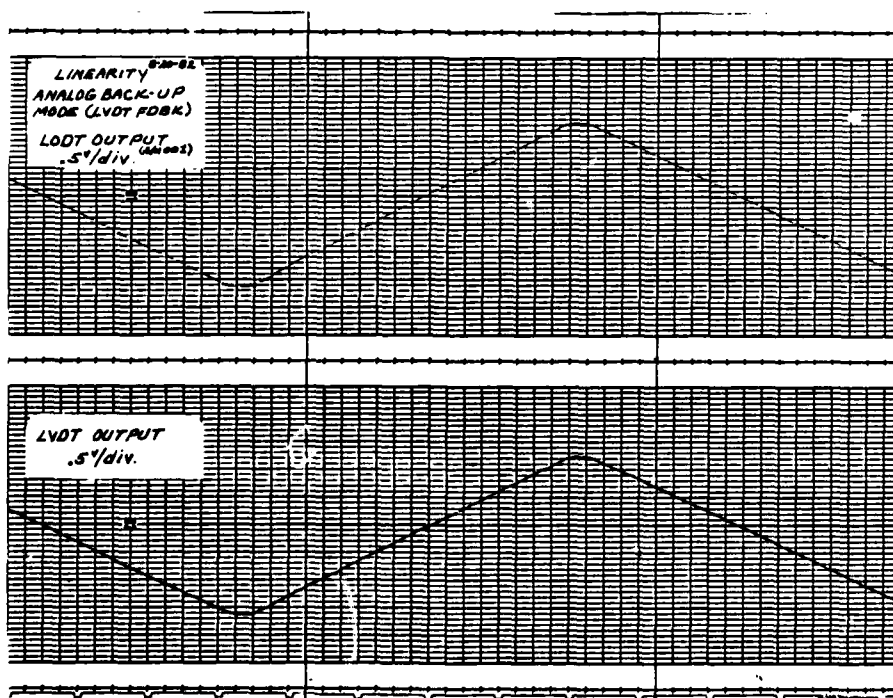


Figure 4-10. Control Loop Linearity, Analog Back-Up Mode With LVDT Feedback

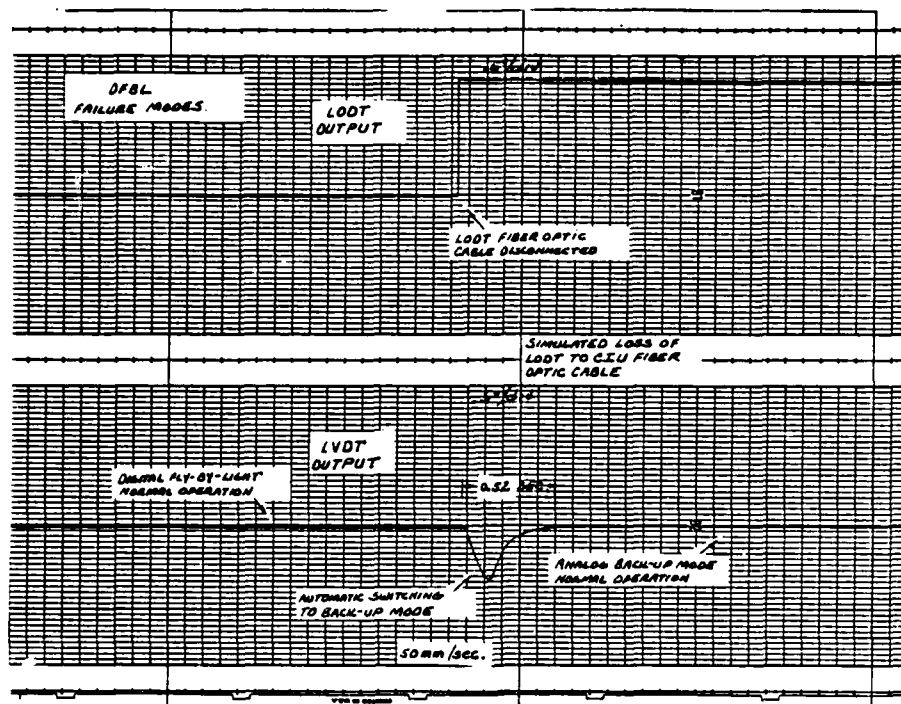


Figure 4-11. DFBL To ABU Automatic Switching -  
Simulated Loss of LODT to CIU Fiber Optic Cable

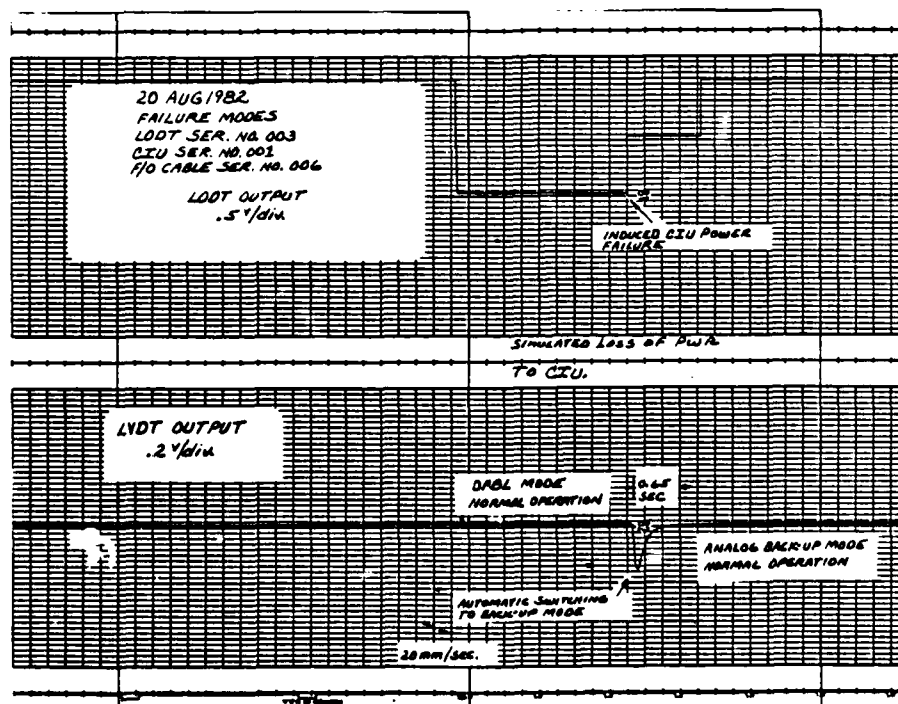


Figure 4-12. DFBL To ABU Automatic Switching -  
Simulated Loss of Power to CIU

TABLE 4-1  
Motor Coil Currents, System Null

<u>COIL</u>	<u>DFBL MODE</u>	<u>ABU MODE</u>
#1	6 ma.	14 ma.
#2	5 ma.	15 ma.
#3	6 ma.	7.5 ma.
#4	9.5 ma.	.3 ma.

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## 5.0 FLIGHT TEST PROGRAM

### 5.1 AIRCRAFT INSTALLATION

The aircraft rudder actuation equipment locations are shown in Figure 5-1 and the pilot's cockpit instrument panel showing the controls and indicators used in the Digital Fly-By-Light system are shown in Figure 5-2. Additions and modifications to the microcomputer, necessary to accommodate the LODT are included in Appendix A.

#### 5.1.1 Continuity and Power Checks

Aircraft wiring changes peculiar to the LODT and LODT Computer Interface Unit installation were checked for continuity, proper grounds and the presence of electrical power on the appropriate connector pins.

#### 5.1.2 Hydraulic Checks

Procedure details are given in Appendix C. The first task involved filling and bleeding the 8000 psi (55 MPa) system. A bleed valve was installed in the return line in the RH speed brake well. A ground cart was connected to the aircraft and the system was filled with MIL-H-83282 fluid. With 25 psig (.2 MPa) applied to the T-2C reservoir, air was bled from a port on the heat exchanger and from the bleed valve in the return line.

A leak check was made on the 8000 psi (55 MPa) portion of the system. Pressures up to 8000 psi (55 MPa) were applied; no external leakage occurred. Pressure was increased sufficiently to operate the test system relief valve (9000 psi/62 MPa). No leakage or malfunctions were observed.

#### 5.1.3 System Checkout

Procedure details are given in Appendix C. A pressure of 25 psig was applied to the T-2C reservoir. With electrical power on the aircraft, the motor/pump unit was energized. The cockpit gage was observed to read 8000 psig (55 MPa). Operation of the 8000 psi (55 MPa) hydraulic system was satisfactory; no malfunctions or leaks occurred.

Force was alternately applied to the rudder pedals in both the DFBW and ABU modes. The proper rudder deflections were visually monitored and the corresponding voltages and Light Emitter Diode (LED) indications verified on the AFCAS test box.

Rudder control was smooth and positive. A small amount of hysteresis was noted due to normal friction in the cables, pulleys, and bellcranks used in the T-2C directional system as follows:

- Dead band at 0° rudder
  - o With cable/pulley friction (no pedal corrections) 10
  - o With cable/pulley friction minimized (pedals alternately tapped lightly) 1/40

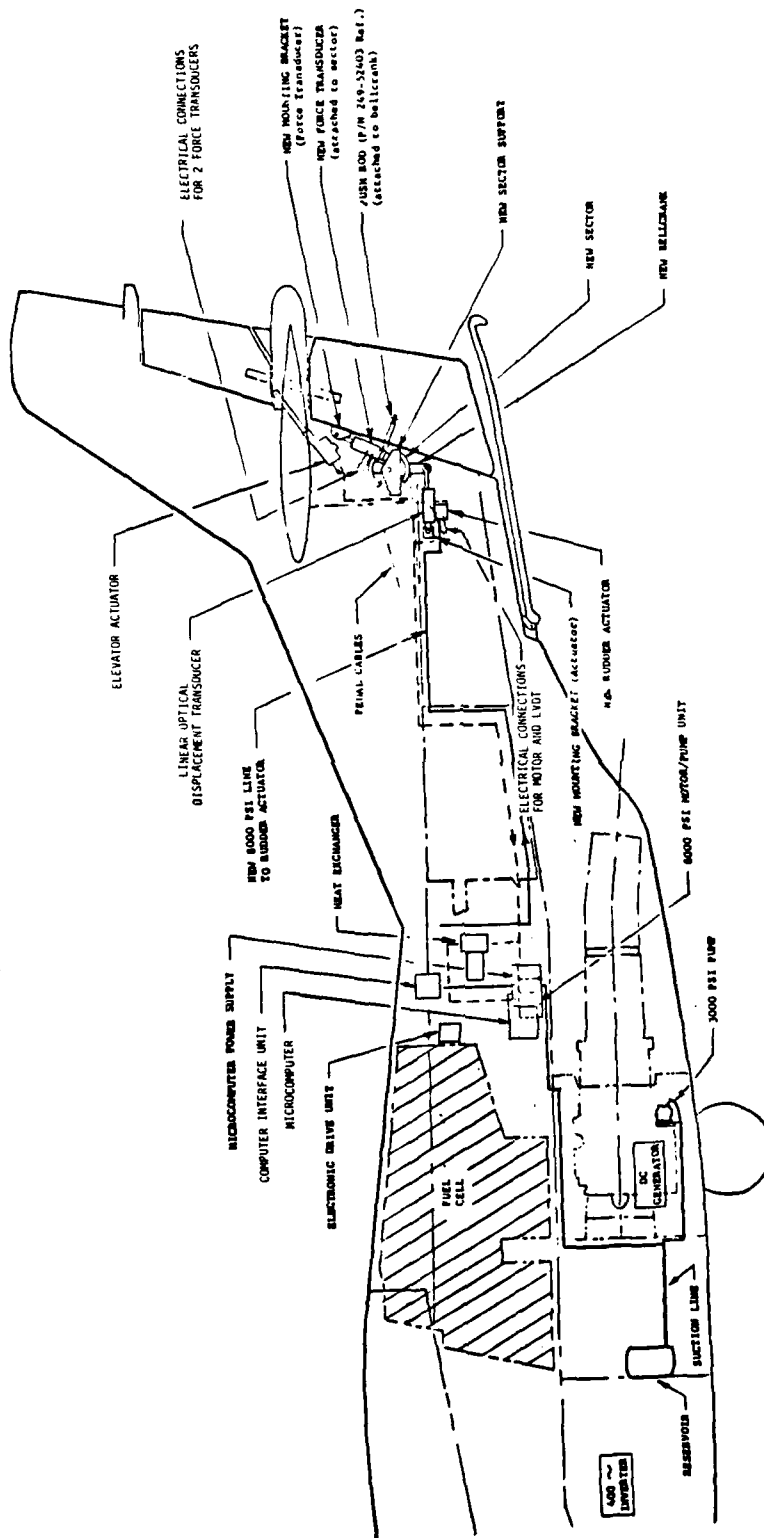


Figure 5-1. T-2C Aircraft DFBL Equipment Location

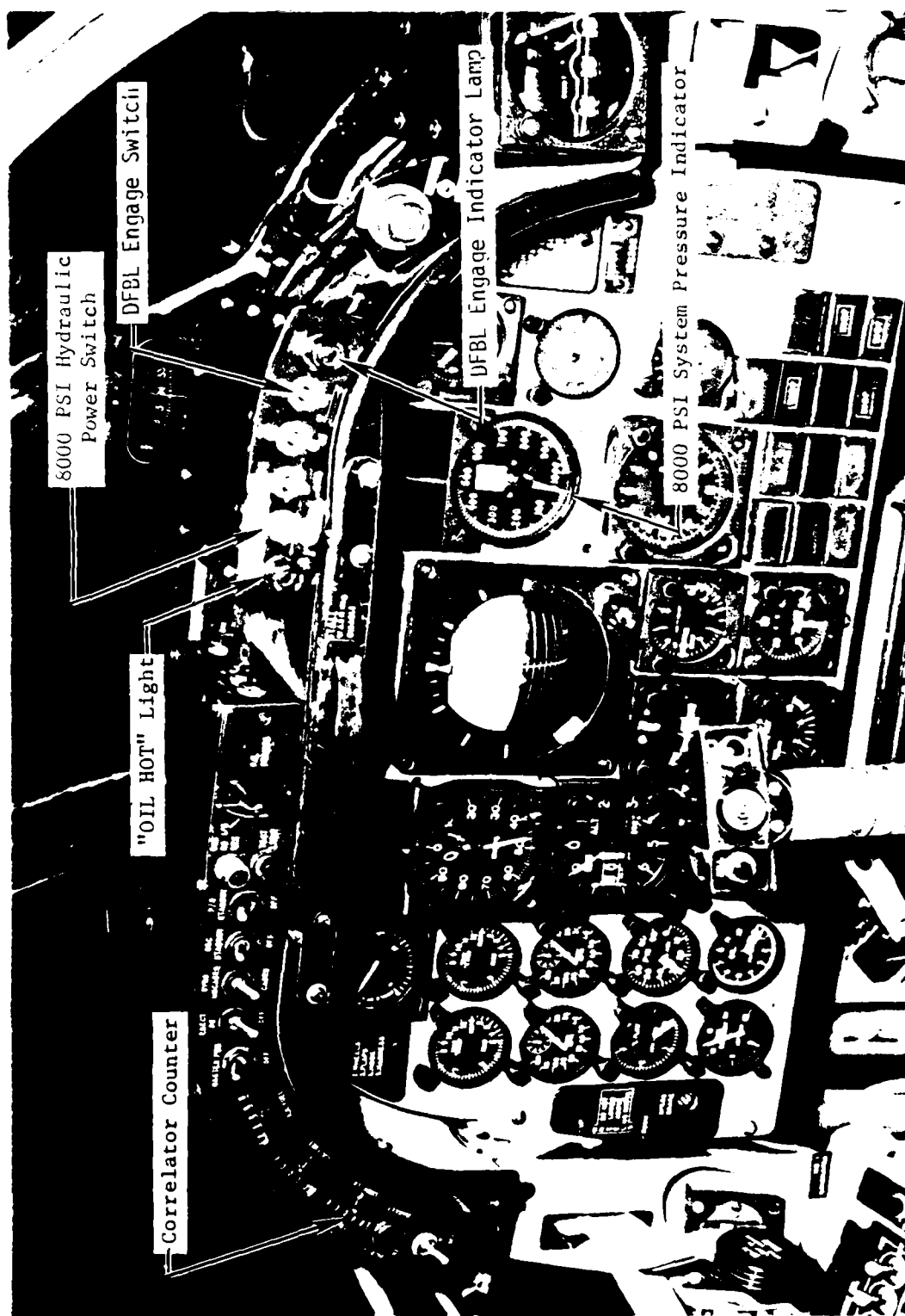


Figure 5-2. Cockpit Instrument Panel

No problems were encountered with the foregoing steps, and all of the data were satisfactory.

## 5.2 INSTRUMENTATION

### 5.2.1 Description

The T-2C was equipped with several flight data acquisition systems. Two were used in the digital AFCAS program: (1) an 18 channel telemetry system, and (2) a 21 hole photo recorder system. The telemetry oscillator package was located in the aft cockpit seat and the photo recorder panel, Figure 5-3, was installed in the nose.

Telemetry data were recorded at the NAAO-C Telemetry and Data Processing Center, Figure 5-4, where a UHF receiving/tracking system provided real-time data acquisition and direct read-out on strip charts. Audio communication with the pilot was available for convenience and safety monitoring.

Pilot instrumentation controls were located above the cockpit instrument panel, Figure 5-2, and on the control stick. Data in the two recording systems were related by means of correlator numbers printed on the photo recorder film, and correlator blips on the telemetry (TM) strip chart. A correlator counter could be read by the pilot for reference purposes.

Flight data parameters instrumented in the T-2C for the digital AFCAS program are listed in Appendix C. Operating range, accuracies, and response capabilities are also given.

### 5.2.2 Instrumentation Ground Checkout

Instrumentation operation and parameter calibrations were verified in the hangar and also during a 30-minute ground run in the DFBL mode with the aircraft engines operating. System operation was normal and all readings were within prescribed limits.

## 5.3 FLIGHT PLAN

The primary objective of the Flight Test Program was to evaluate the operation of the MIL-T-85289 Linear Optical Displacement Transducer (LODT) as an active sensing unit of the Advanced Flight Control Actuation System in a T-2C aircraft. Approximately three flight hours were deemed sufficient to evaluate the LODT performance in an aircraft flight environment, confirm prior analyses and laboratory tests, and establish a measure of confidence in system reliability. The flight plan was designed to exercise the aircraft's rudder control, and therefore the LODT, over a broad range of speed and altitude within the flight envelope of the T-2C. Performance comparisons would be made at each predetermined flight condition, by performing the same maneuvers in both the Digital Fly-By-Light (DFBL) and the Analog Back-Up (ABU) rudder control modes. Details of the flight plan are included in reference C.

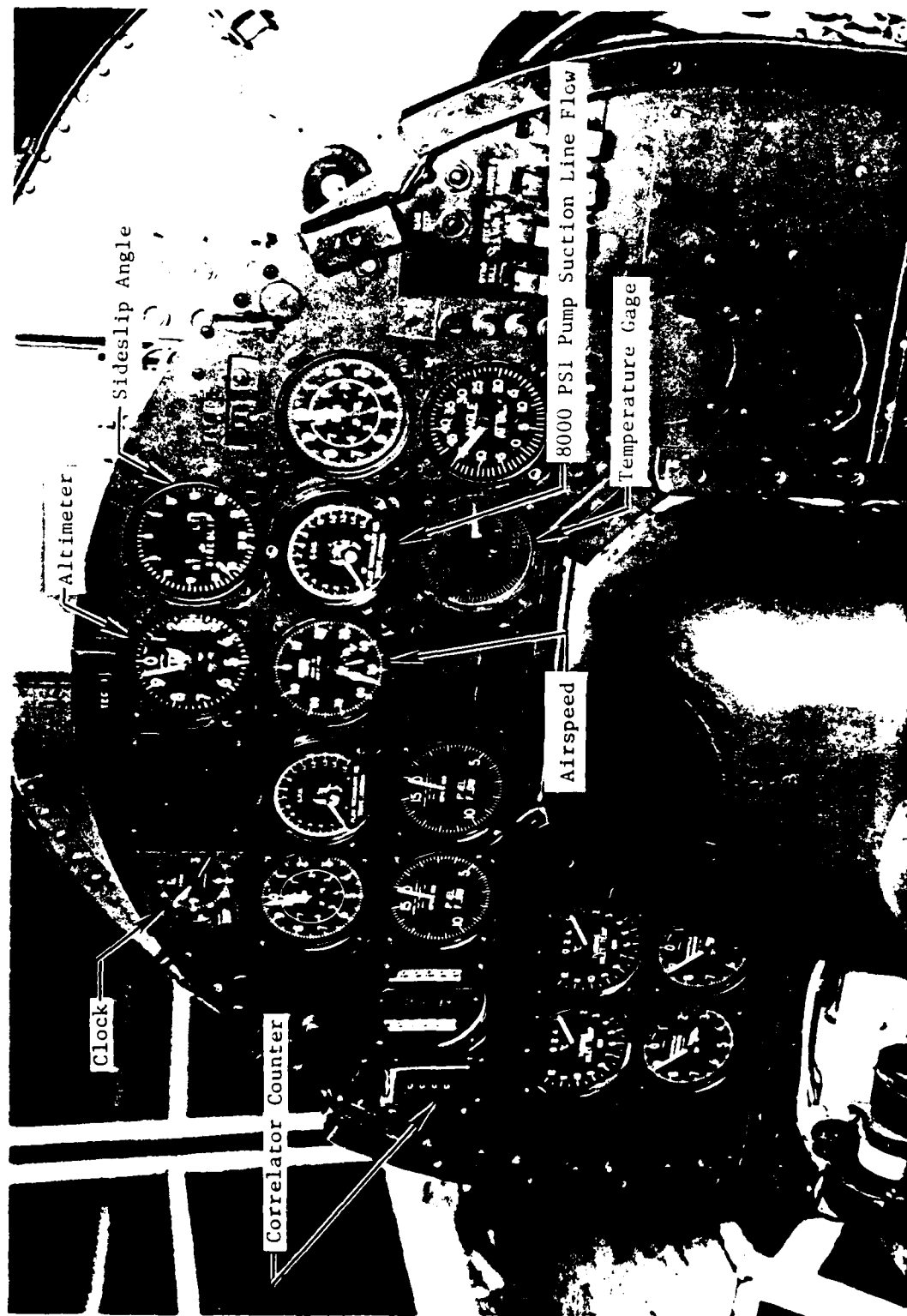


Figure 5-3. Photo Recorder Panel



Figure 5-4. Telemetry and Processing Center

## 5.4 FLIGHT TEST RESULTS

Three flights were flown for a total of 3.6 hours. The pilot noted no transients or differences in aircraft control when switching between the DFBL and ABU control modes. All planned flight conditions, maneuvers, and data acquisitions were executed and no malfunctions occurred.

### 5.4.1 Flight Program Summary

<u>DATE</u>	<u>FLIGHT</u>	<u>DURATION</u>	<u>ALTITUDE</u>	<u>SPEED</u>	<u>Nz (MAX)</u>
2-22-83	1	1.5 hrs.	10,000 ft	150 KOAS	3.0 g
			15,000 ft	150 KOAS	
			15,000 ft	200 KOAS	
			20,000 ft	200 KOAS	
2-22-83	2	0.9 hrs.	10,000 ft	200 KOAS	3.0 g
			10,000 ft	250 KOAS	
			15,000 ft	250 KOAS	
			20,000 ft	150 KOAS	
			20,000 ft	250 KOAS	
2-22-83	3	1.2 hrs.	15,000 ft	300 KOAS	3.0 g
			15,000 ft	340 KOAS	
			20,000 ft	300 KOAS	
			20,000 ft	325 KOAS	
			30,000 ft	150 KOAS	
			30,000 ft	200 KOAS	
			30,000 ft	250 KOAS	

The following maneuvers were executed in the DFBL and ABU control modes at each of the altitudes and airspeeds listed above:

- o Slow Steady Sideslips (Left and Right)
- o Small pulses (Left and Right)
- o Small Doublets (Left and Right)
- o Full Rudder Sideslips & Releases (Left and Right)
- o Full Pulses (Left and Right)
- o Large Doublets (Left and Right)

### 5.4.2 Telemetry Instrumentation Data

Telemetered data was received on all three flights and appears in Figures 5-5A thru 5-10C. The test runs consisted of first executing yaw maneuvers in the Analog Back-Up (ABU) control mode and then repeating the maneuvers in the Digital Fly-By-Light control mode under the same flight conditions. The outputs of both rudder feedback transducers were available at all times, however, the LODT was the active feedback transducer in the DFBL control mode and the LVDT was the active feedback transducer in the ABU control mode. To permit direct comparison of the two transducers, the digital output of the LODT was converted in the microcomputer to an equivalent analog signal.

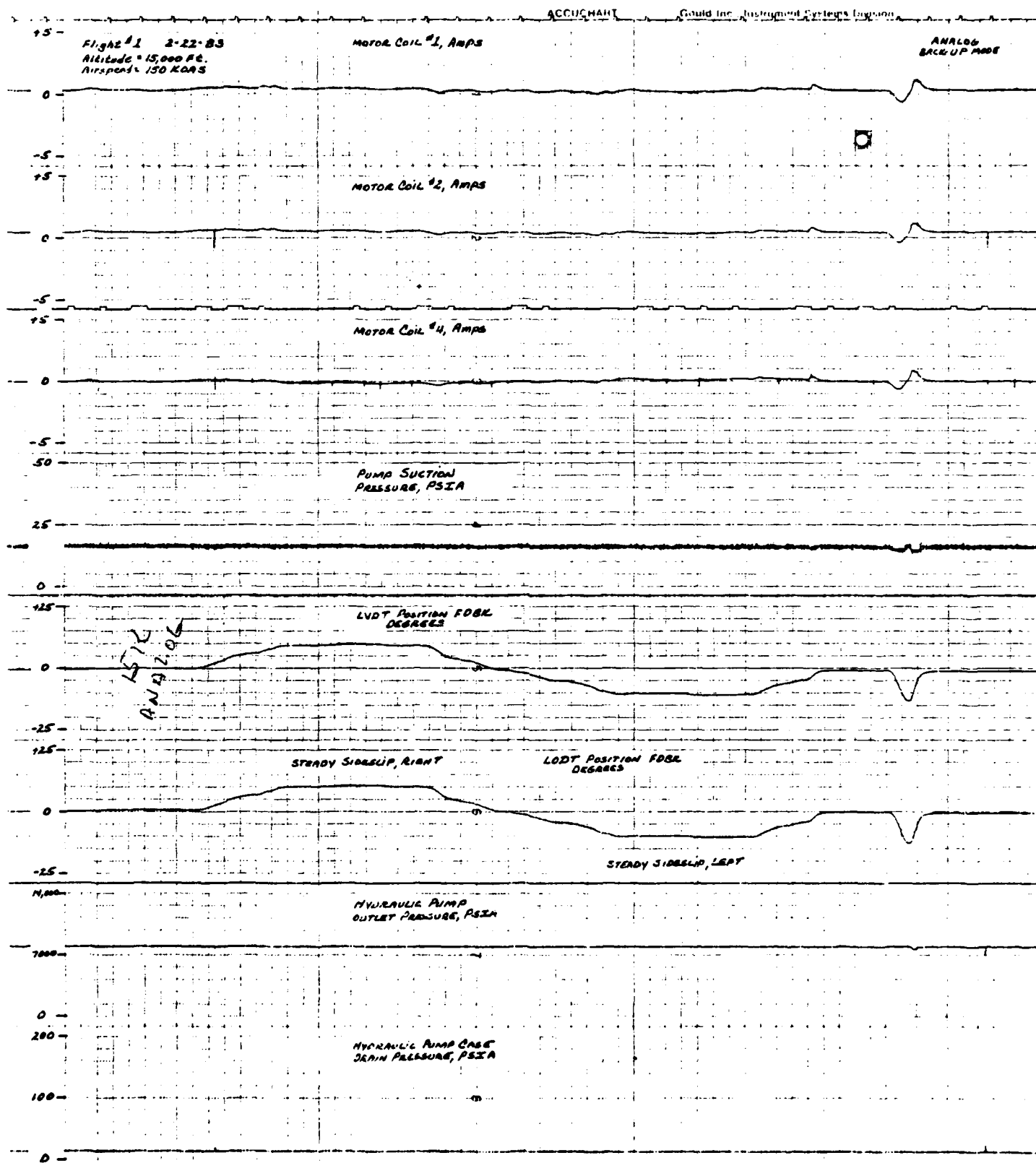


Figure 5-5A. Steady Sideslip, Analog Back-Up Mode - Flight #1 Instrumentation Data

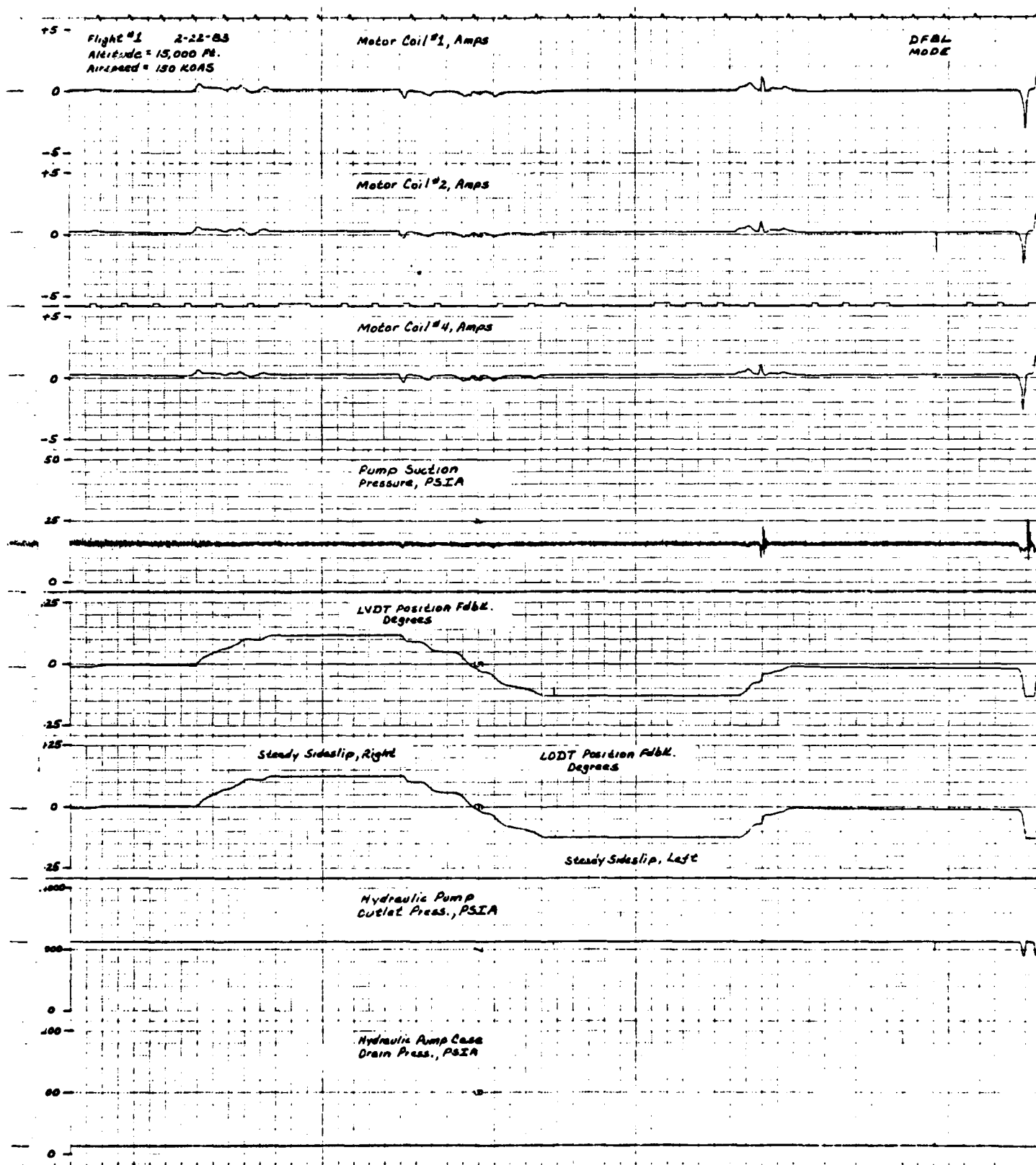


Figure 5-5B. Steady Sideslip, DFBL Mode - Flight #1 Instrumentation Data

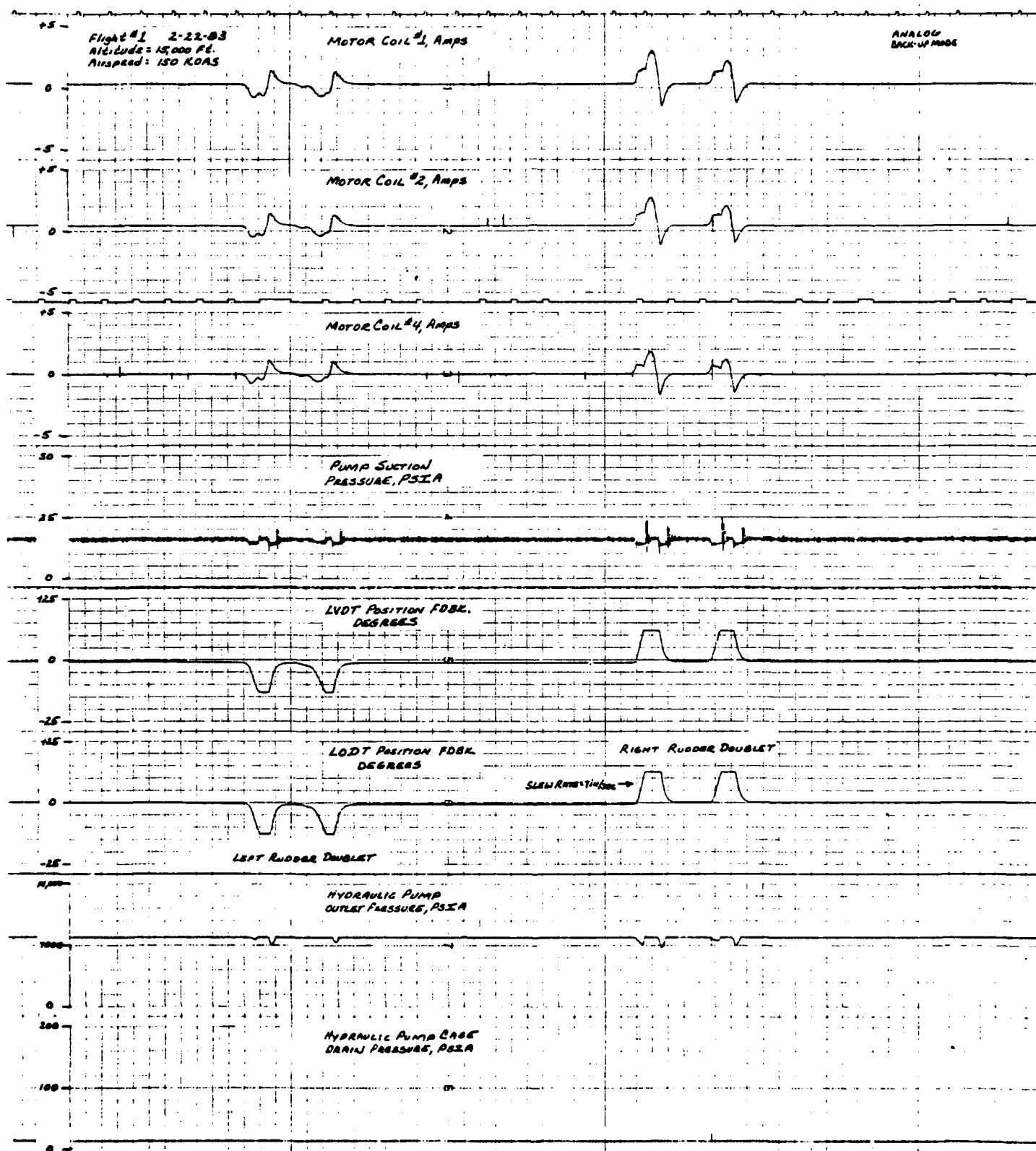


Figure 5-6A. Rudder Doublets, Analog Back-Up Mode - Flight #1 Instrumentation Data

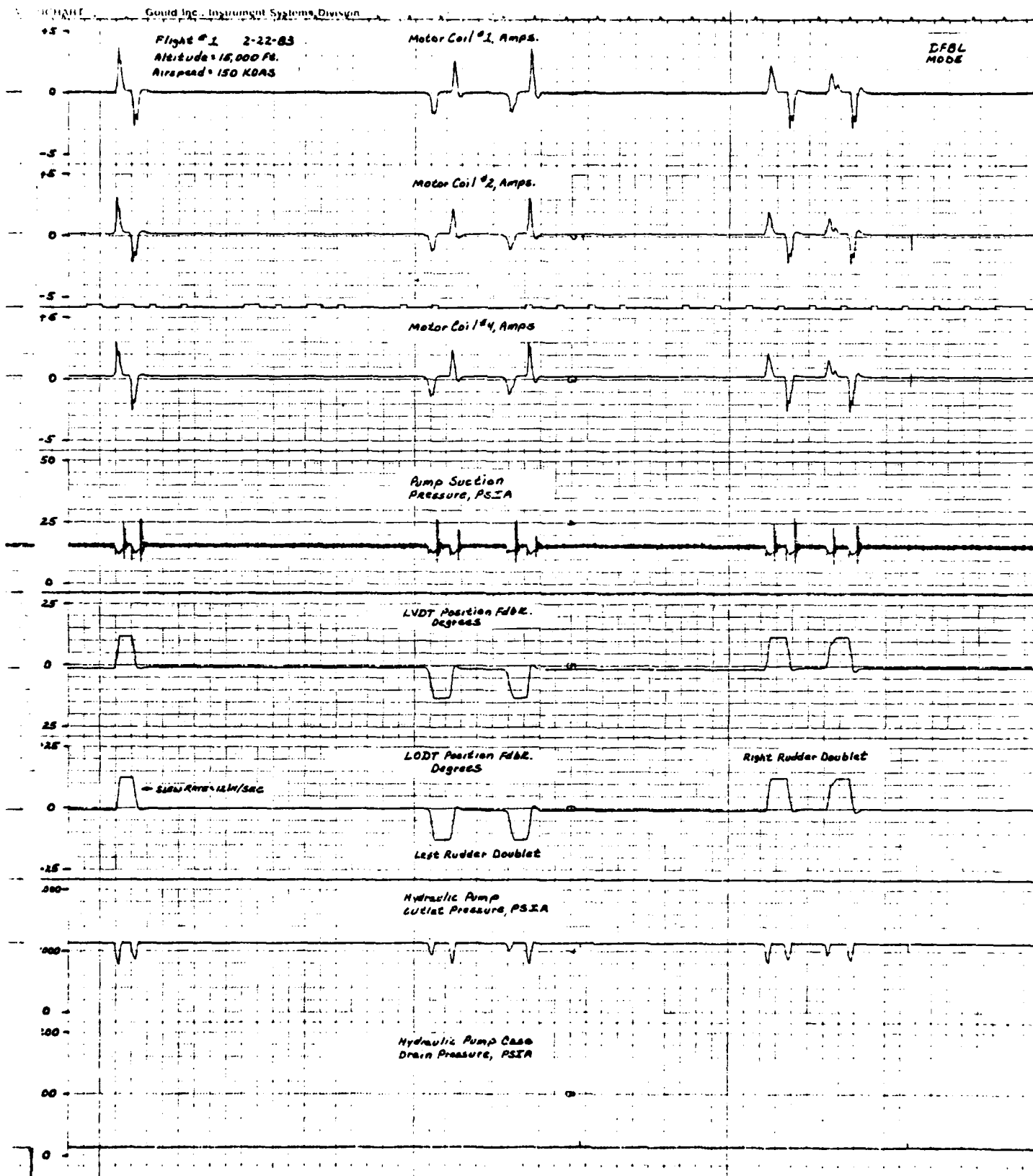


Figure 5-6B. Rudder Doublets, DFBL Mode - Flight #1 Instrumentation Data

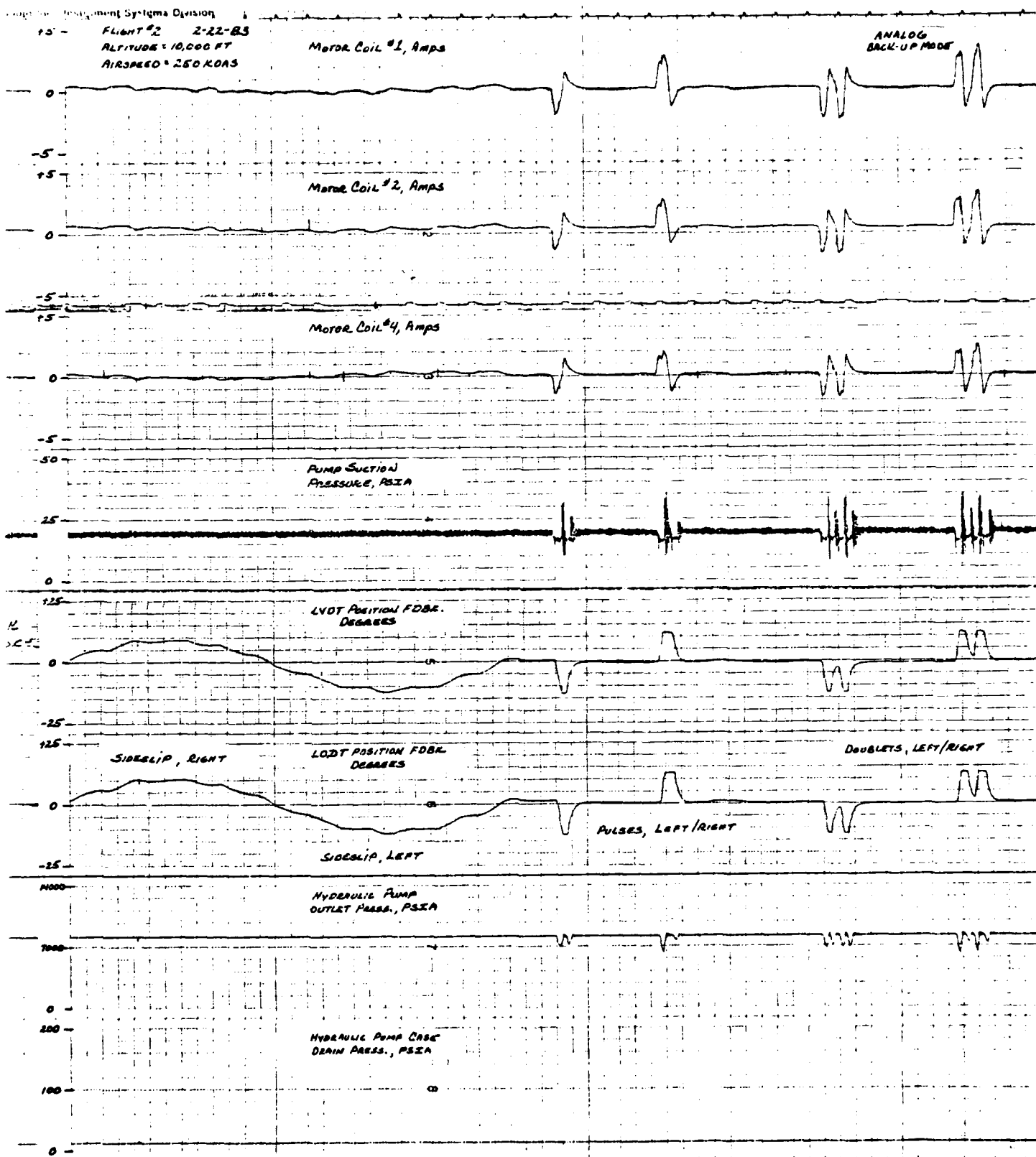


Figure 5-7A. Sideslip-Pulses-Doublets, Analog Back-Up Mode - Flight #2 Instrumentation Data

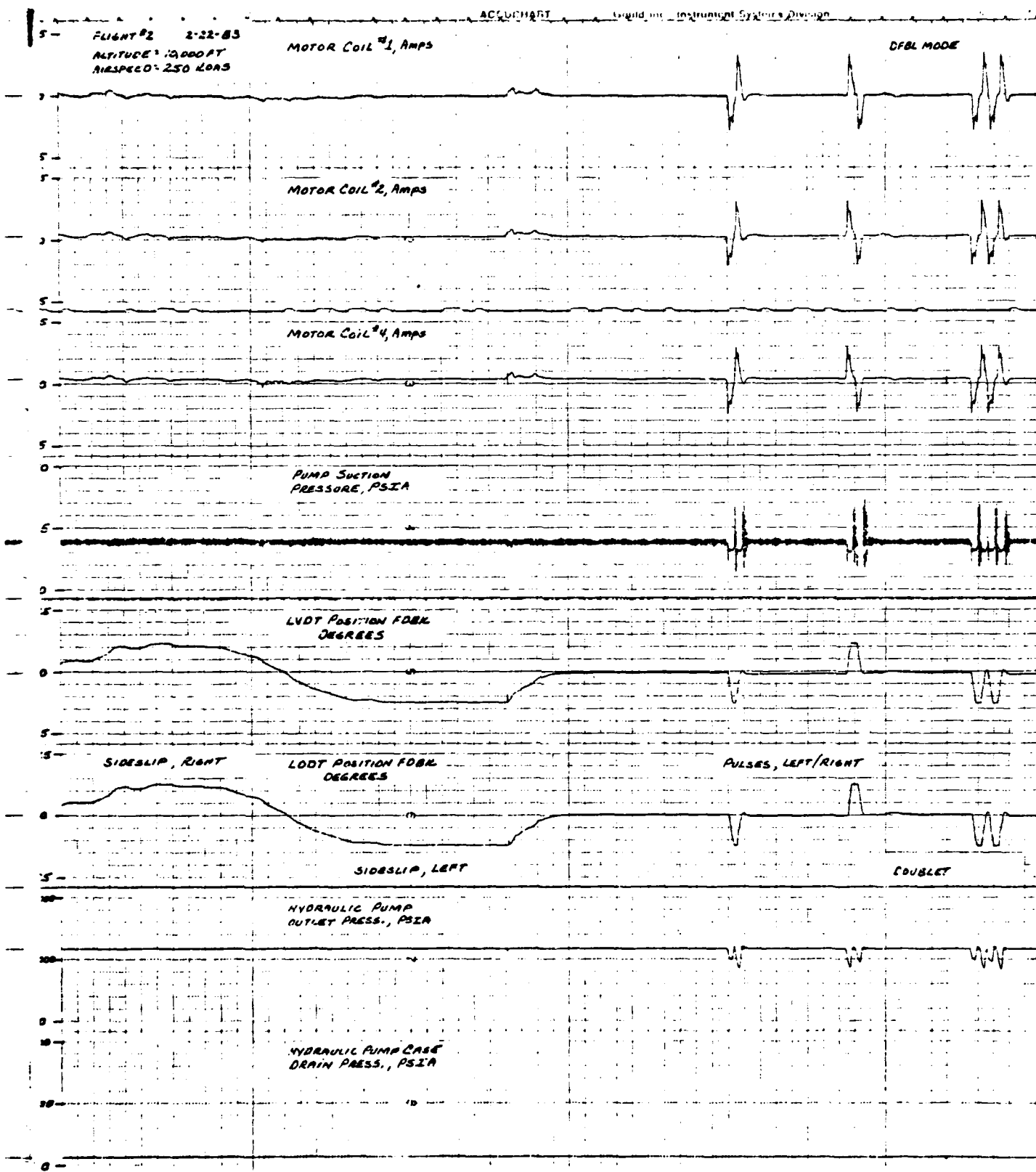


Figure 5-7B. Sideslip-Pulses-Doublets, DFBL Mode - Flight #2 Instrumentation Data

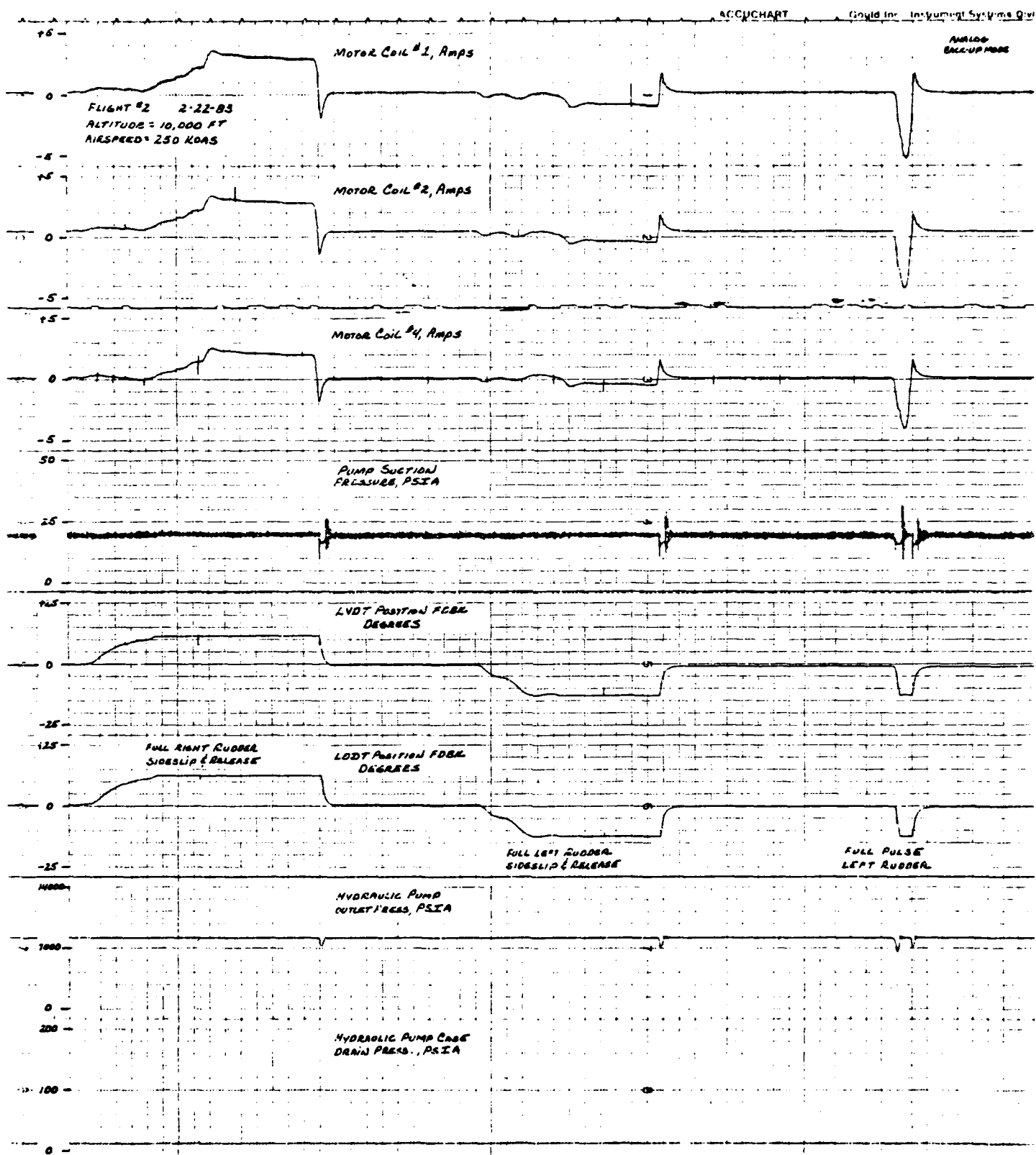


Figure 5-8A. Full Rudder, Sideslip & Release, Analog Back-Up Mode - Flight #2 Instrumentation Data

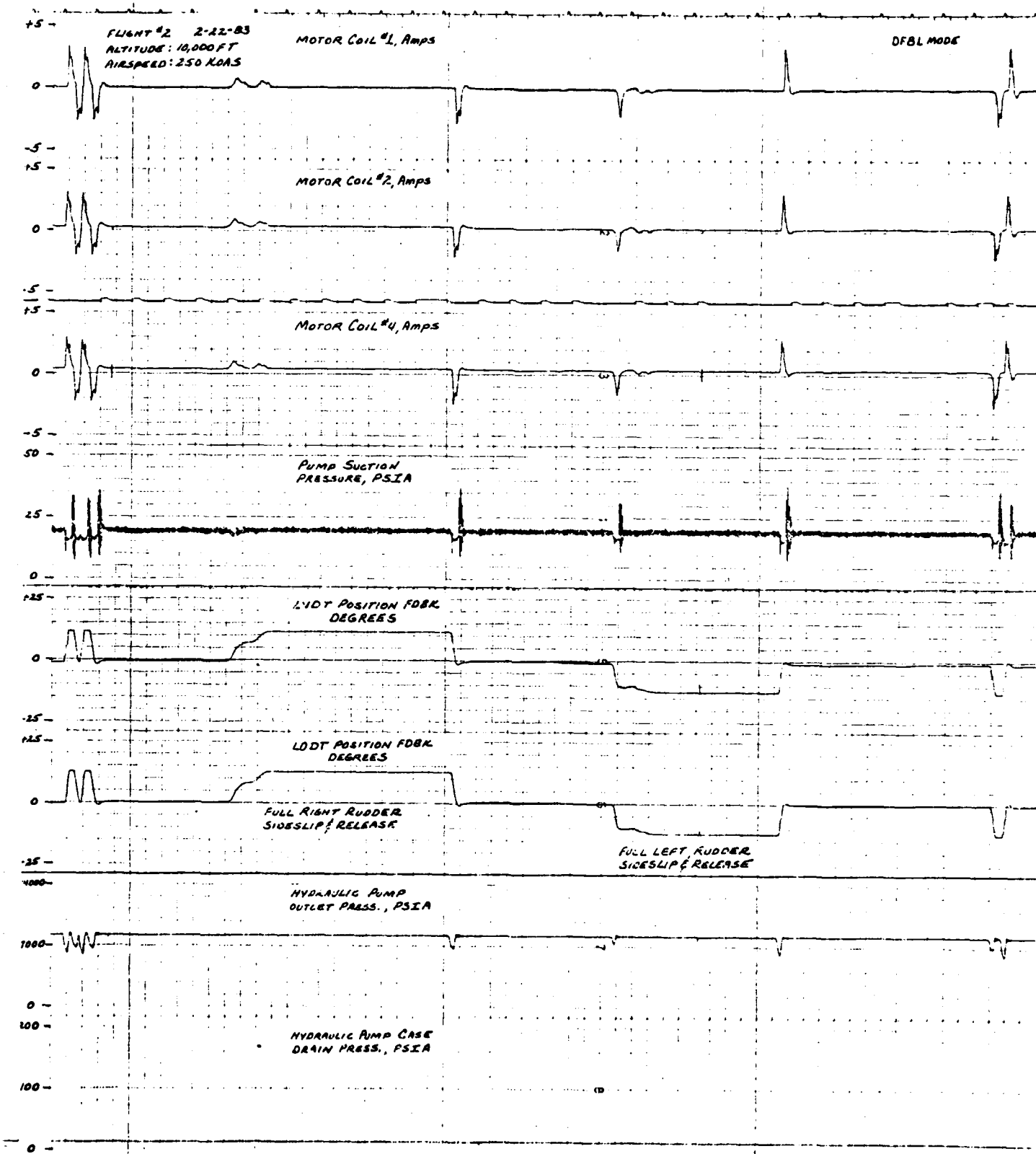
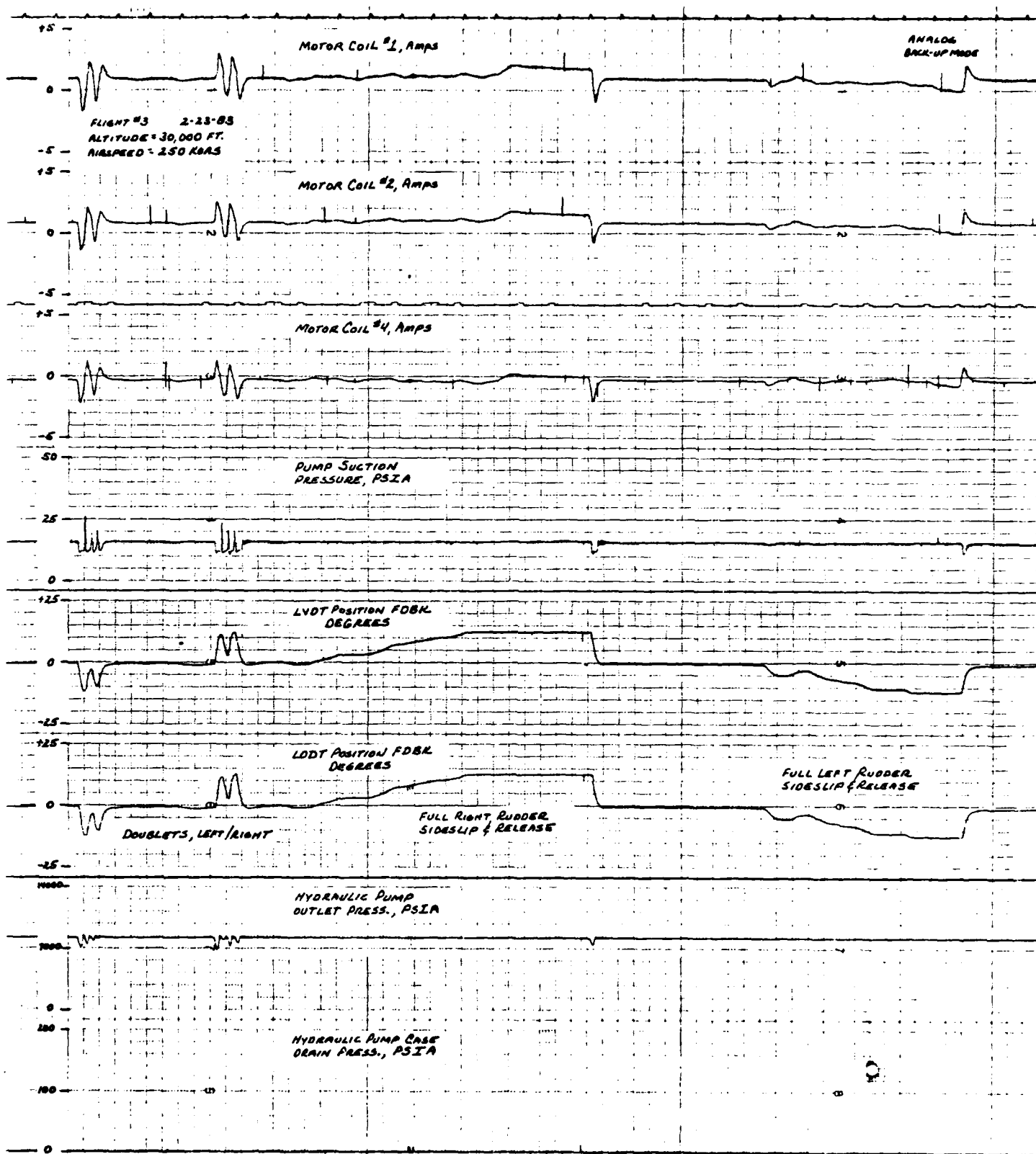


Figure 5-8B. Full Rudder, Sideslip & Release, DFBL Mode - Flight #2 Instrumentation Data



Flight 5-9A. Full Rudder, Sideslip & Release, Analog Back-Up Mode -  
Flight #3 Instrumentation Data

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(Gould Inc. Instrument Systems Division)

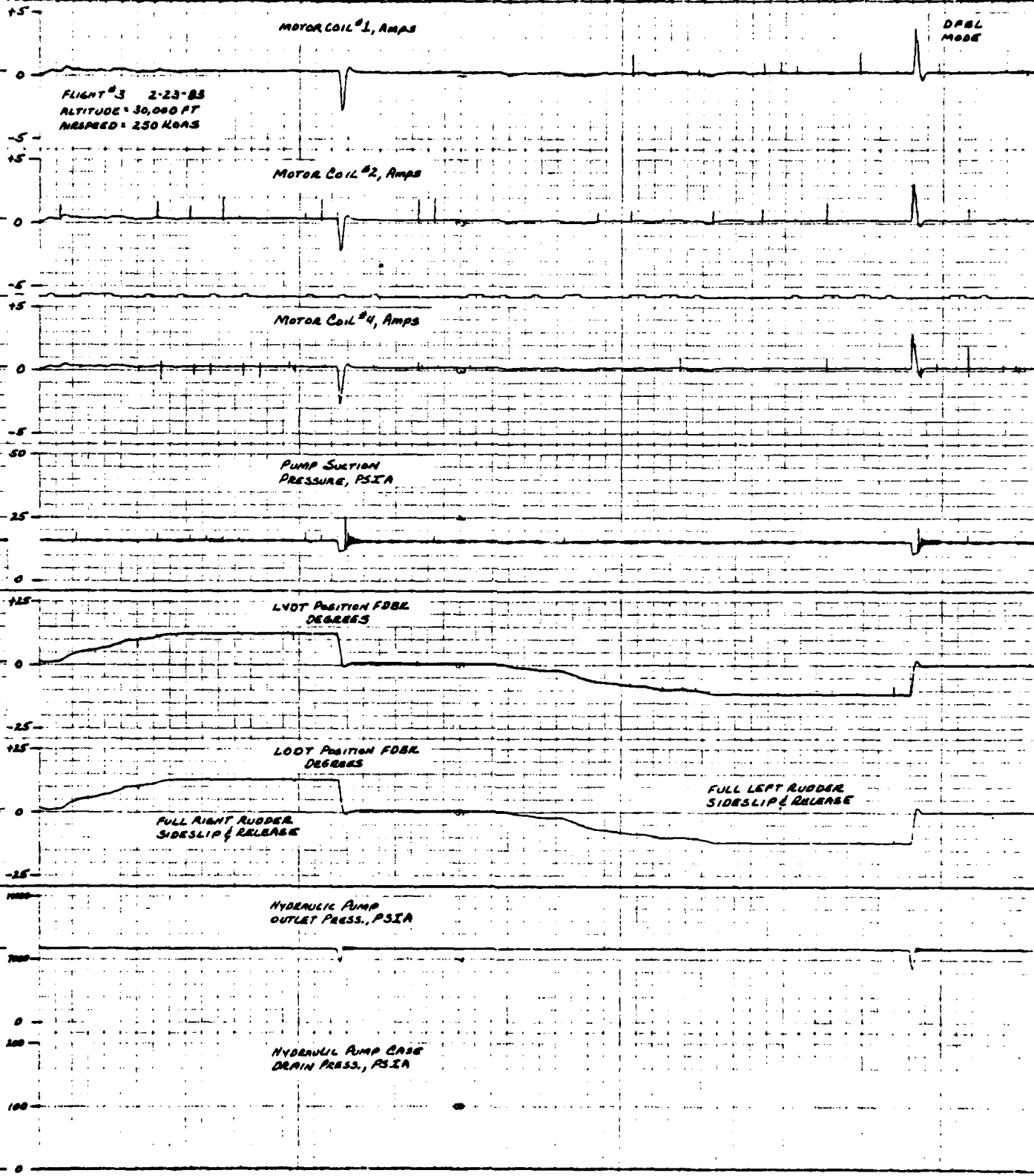


Figure 5-98. Full Rudder, Sideslip & Release, DFBL Mode - Flight #3 Instrumentation Data

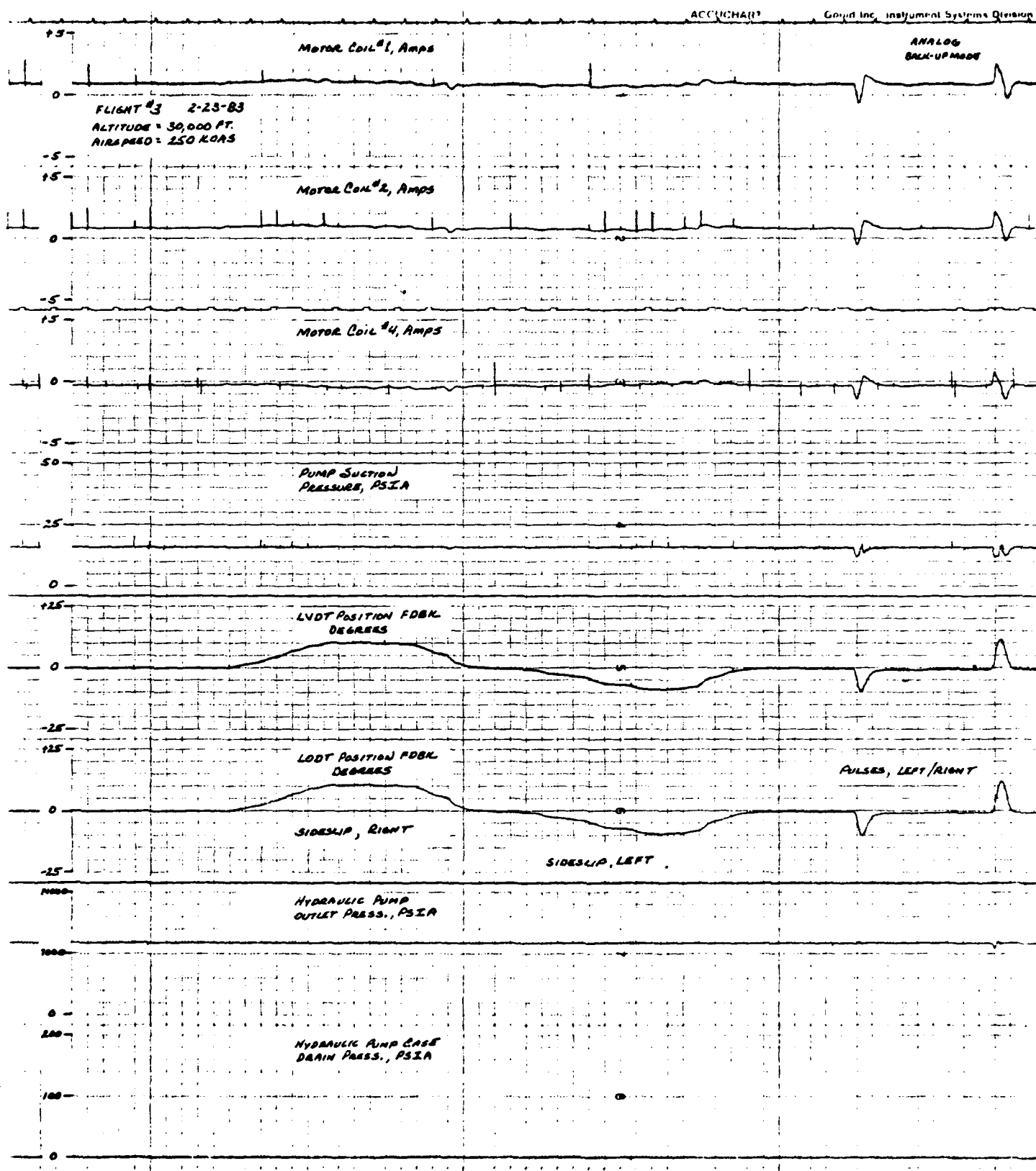


Figure 5-10A. Sideslips-Pulses, Analog Back-Up Mode - Flight #3 Instrumentation Data

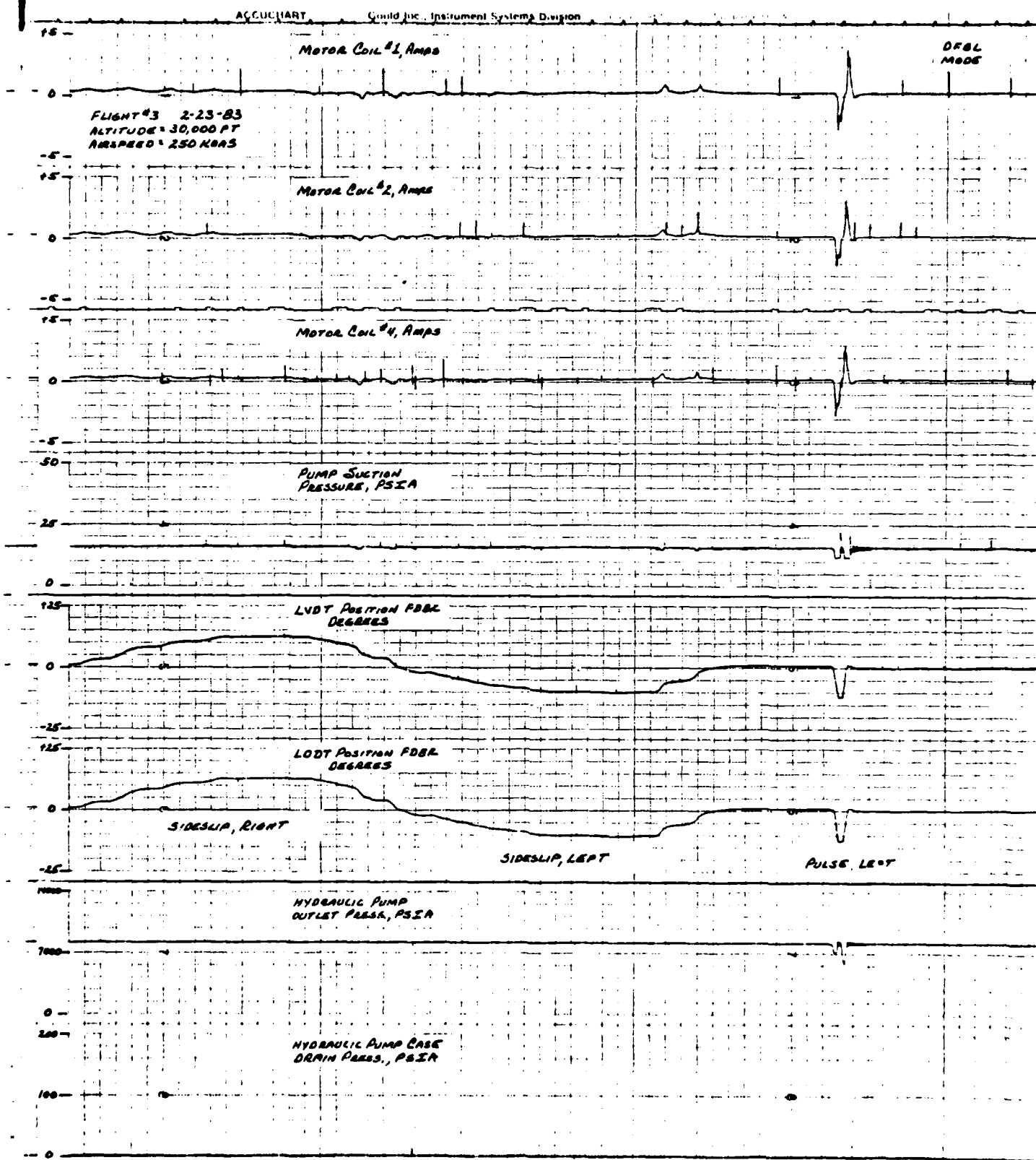


Figure 5-108. Sideslips-Pulses, DFBL Mode - Flight #3 Instrumentation Data

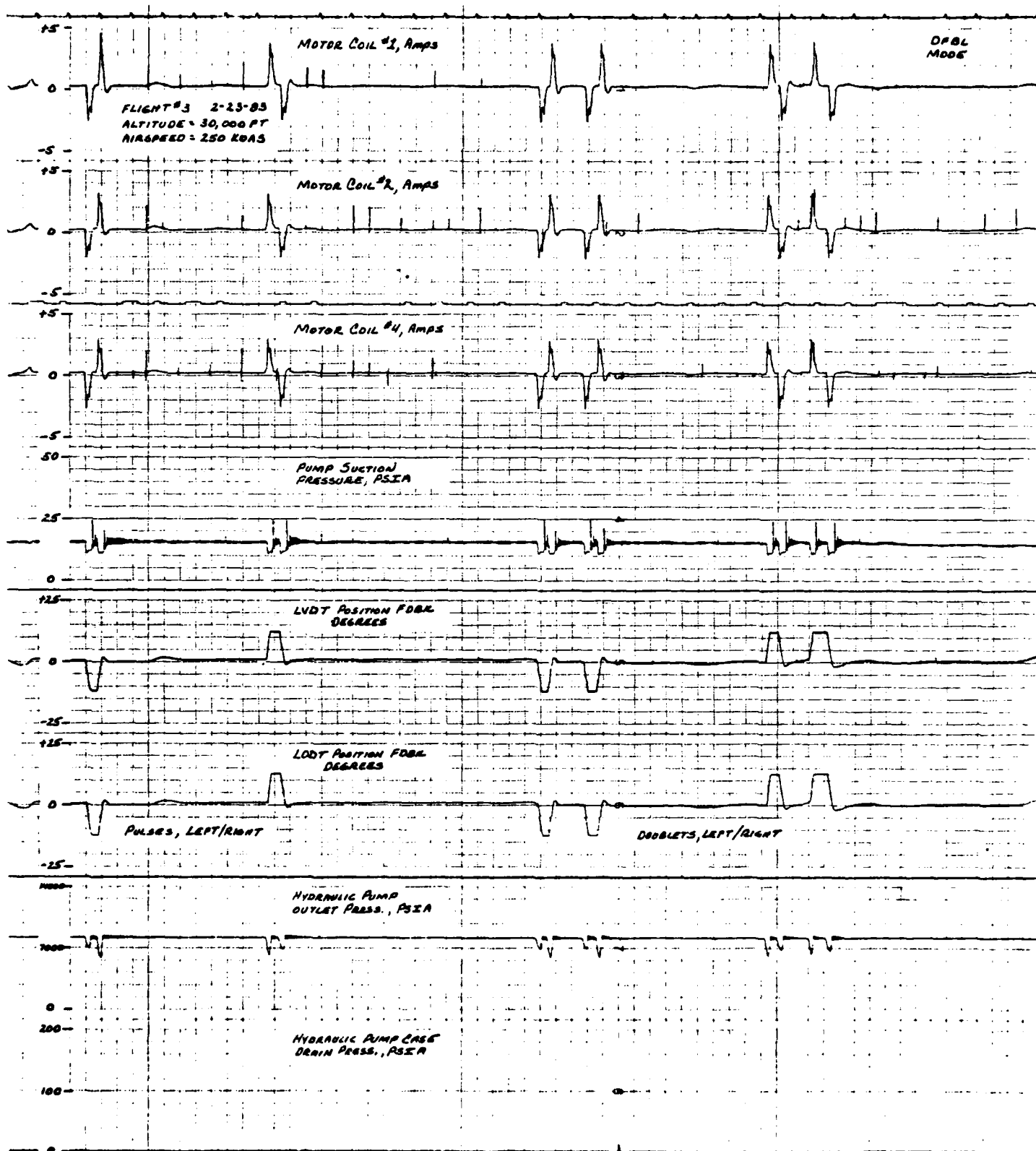


Figure 5-10C. Rudder Pulses & Doublets, DFBL Mode - Flight #3 Instrumentation Data

Examination of Figures 5-5A thru 5-10C shows excellent correspondence between the LODT and LVDT outputs during both control modes and all yaw maneuvers. Response in the ABU mode (Figures 5-6A example) exhibited a critically damped system having no overshoot with a maximum slew rate of approximately 7 inches/second (17.8 Cm/second). Response in the higher bandpass DFBL mode (Figure 5-6B example) exhibited a slightly underdamped system with a maximum slewing rate of approximately 12 inches/second (30.5 Cm/second), or about 80% of the transducer's maximum required slewing rate of 15 inches/second (38.1 Cm/second).

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## 6.0 CONCLUSIONS AND RECOMMENDATIONS

The Linear Optical Displacement Transducer (LODT) represents a viable approach to EMI immunity in advanced aircraft since the transducer itself requires no electrical power and transmits digital position data via optical fibers. The results of the flight test evaluation demonstrate that the LODT and its associated Computer Interface Unit and Fiber Optics Cable performed satisfactorily and reliably as the active position feedback device in the directional flight control loop of the T-2C airplane. Laboratory frequency and step response data with the LODT in the feedback path of the AFCAS actuation system indicated satisfactory and identical performance with that obtained with a conventional LVDT. Operating time on the LODT equipment was in excess of 25 hours, which included laboratory tests, aircraft ground tests and 3.6 flight hours, with no failures attributable to the LODT equipment.

As with all developmental devices employing new technologies and processes, improvements, from a user's standpoint, can always be suggested and are presented below.

### 1. Overtravel Digital Output

The digital output in the fully extended position where all binary 1's are present, changes abruptly to all binary 0's in the overtravel. All binary 1's should continue throughout the extended position overtravel to preclude erroneous full scale commands to the system in the event the transducer is driven into the overtravel.

### 2. Transducer Fiber Optic Receptacle/Housing

The fiber optic receptacle and its housing add considerably to its envelope. A circular end connector arrangement would not only reduce the envelope but also remove present limitations in actuator mounting orientation.

### 3. Rod End Attachment

Provisions should be made for a simplified "floating" attachment to the actuator piston rod similar to that used on LVDT's.

### 4. Fiber Optic Cable Connector

Installations in aircraft are typically densely packed and most often not easily accessible. Many times a connector is mated to equipment by "feel" only. The fiber optic connector is secured to the LODT by two Allen head screws which are difficult to tighten, and the Allen wrench, if dropped, would be difficult, if not impossible, to retrieve, creating a potential hazard. A circular MIL-STD type fiber optics connector would alleviate these problems.

5. Computer Interface Unit (CIU)

Significant reduction in the size of the CIU and a reduction in the number of interconnecting optical fibers through the use of serialized data would be highly desirable features of future generation optical transducers.

## REFERENCES

### Reference No.

1. NAC-TR-2334, Development of a Prototype Linear Optical Displacement Transducer for Flight Control System Evaluation, United Technologies Corporation, Hamilton Standard Division, Contract N00163-80-C-0080, August 1982, Unclassified.
2. NR72H-240, Feasibility Study for Advanced Flight Control Actuation System (AFCAS), Rockwell International Corporation, Columbus Aircraft Division, Contract N62269-72-C-0108, June 1972, Unclassified. AD 767 058
3. NR73H-107, Control-By-Wire Actuator Model Development for AFCAS, Rockwell International Corporation, Columbus Aircraft Division, Contract N62269-73-C-0405, January 1974, Unclassified. AD 772 588
4. NR75H-1, Control-By-Wire Modular Actuator Tests (AFCAS), Rockwell International Corporation, Columbus Aircraft Division, Contract N62269-73-C-0405, January 1975, Unclassified. AD A-006 371
5. NR76H-1, Design and Fabrication of an 8000 psi Control-By-Wire Actuator for Flight Testing in a T-2C Airplane, Rockwell International Corporation, Columbus Aircraft Division, Contract N62269-75-C-0311, January 1976, Unclassified. AD A024 487/ICI
6. NAVAIRDEVCON 75287-60, Flight Verification of the Advanced Flight Control Actuation System (AFCAS) in the T-2C Aircraft, Columbus Aircraft Division, Rockwell International Corporation, Contract N62269-76-C-0201, June 1978, Unclassified.
7. NAVAIRDEVCON 78207-60, Flight Verification of Direct Digital Drive for an Advanced Flight Control Actuation System (AFCAS) in the T-2C Aircraft, North American Aircraft Division, Rockwell International Corporation, Contract N62269-76-C-0201, November 1979, Unclassified.

8. NAVAIRDEVCON 79156-60, Design and Test of a Hydra-Optic Flight Control Actuation System (HOF-CAS) Concept, North American Aircraft Division, Rockwell International Corporation, Contract N62269-79-C-0709, September 1979, Unclassified.
9. Rockwell Letter 82CL 1797, Summary Report of a Flight Evaluation of the Direct Digital Fly-By-Light Actuation System, North American Aircraft Division, Rockwell International Corporation, Contract N62269-81-M-3030, March 1981, Unclassified.

## APPENDIX A

### MICROCOMPUTER ASSEMBLY

The microcomputer used for this program is based on the Motorola MC6800 microprocessor. The assembly consisted primarily of the Motorola Monoboard Microcomputer 1A (Micromodule 1A) which is a complete computer-on-a-board, plus Burr-Brown D/A and A/D converters, and a Gray-To-Binary code converter, all mounted on a mother board and housed in a single unit. This unit, shown in Figure A-1, contains all the interfaces and wiring required for the processor.

The heart of the unit is the monoboard microcomputer which has the following features:

- MC6800 Microprocessing Unit (MPU) with associated clock oscillator, power on reset timer, and memory decoding logic.
- 1024 Bytes of RAM.
- Sockets for up to 4096 bytes of Alterable Read Only Memory (AROM) or mask-programmable ROM (Four of the 2048 x 8-bit ROM's may also be used if the proper jumper connections are made, thus providing over 8K of ROM on this module).
- One RS-232C compatible interface that utilizes a single MC6850 (ACIA).
- Two programmable MC6820 PIA's that provide 40 programmable Input/Output and control lines.
- Address, data, and control bus drivers to interface Monoboard Microcomputer 1A with other modules in the Family or with an EXORciser.
- TTL signal level inputs and TTL signal level, three-state, or open collector outputs.

This monoboard microcomputer is shown in block diagram form in Figure A-2. A photograph of the board is shown in Section 3.2.7 of the main report.

The MPU is contained on a single chip on the board and is the Motorola MC6800 MPU. The complete instruction set is given in Tables A-I, A-II, and A-III.

The A/D, D/A and Gray-to-Binary converters make up the other three circuit boards in the microcomputer assembly. Figures A-3 and A-4 show the block diagrams of the A/D and D/A converters, respectively. Characteristics of the A/D and D/A converters are given in Table A-IV.

To incorporate the Linear Optical Displacement Transducer (LODT) and Computer Interface Unit (CIU) into the T-2C Digital Fly-By-Light (DFBL) system, modifications to the microcomputer assembly were required. These modifications included:

- o Addition of a 22-pin electrical connector to interface with the CIU.

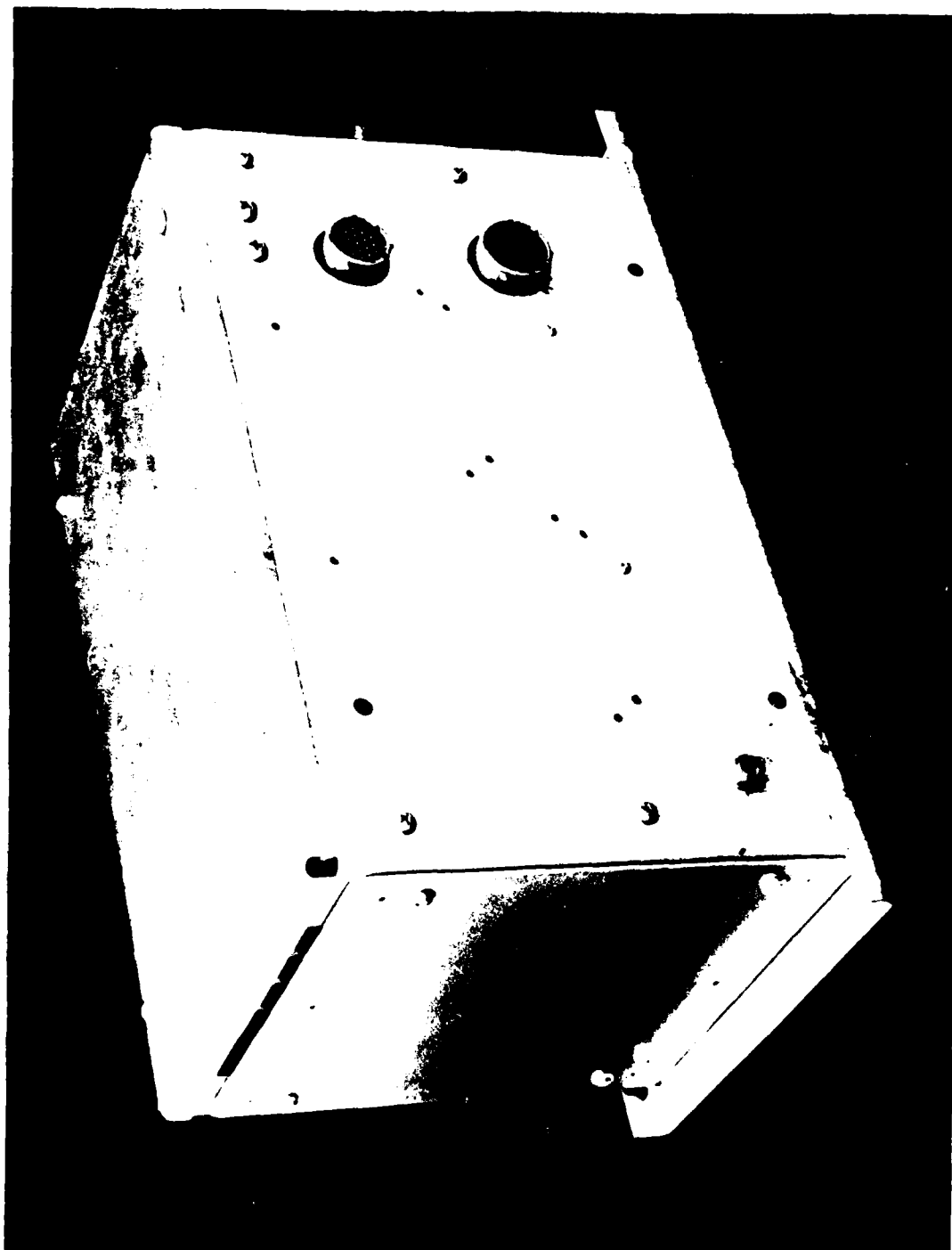


Figure A-1. Motorola Microcomputer Unit

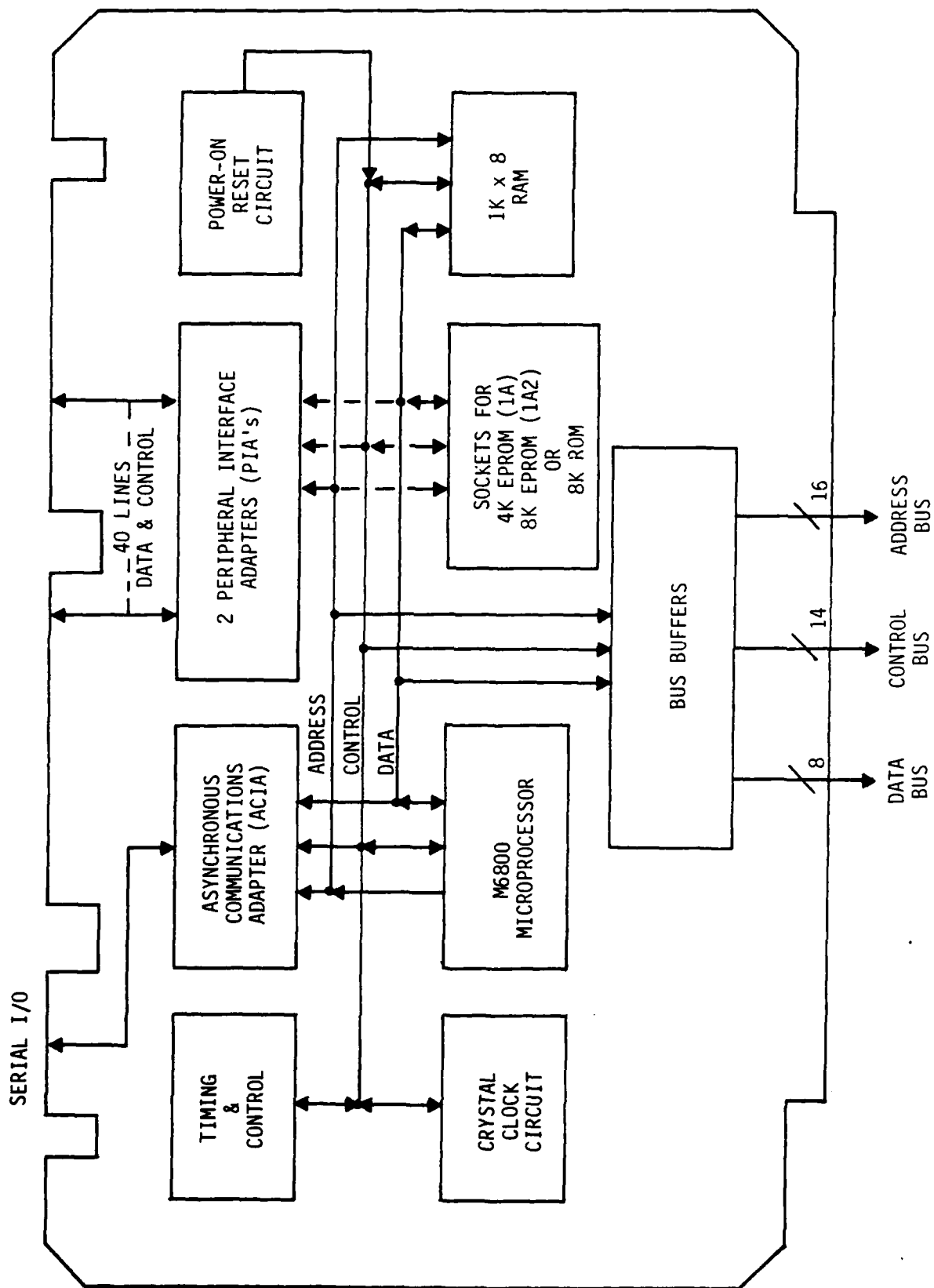


Figure A-2. Monoboard Microcomputer

Table A-I. Accumulator and Memory Instructions (MC 6800)

ADDRESSING MODES										BOOLEAN/ARITHMETIC OPERATION	COND CODE REG							
OPERATIONS	MNEMONIC	IMMED		DIRECT		INDEX		EXTND		IMPLIED		(All register labels refer to contents)	H	I	N	Z	V	C
		OP	~	OP	~	OP	~	OP	~	OP	~							
Add	ADDA	38	2 2	98	3 2	A8	5 2	B8	4 3			A ← M ← A	1	0	1	1	1	1
	ADDB	C8	2 2	D8	3 2	E8	5 2	F8	4 3			B ← M ← B	1	0	1	1	1	1
Add Accum	ABA							18	2 1			A ← B ← A	1	0	1	1	1	1
Add with Carry	ADCA	89	2 2	99	3 2	A9	5 2	B9	4 3			A ← M ← C ← A	1	0	1	1	1	1
	ADCB	C9	2 2	D9	3 2	E9	5 2	F9	4 3			B ← M ← C ← B	1	0	1	1	1	1
And	ANDA	84	2 2	94	3 2	A4	5 2	B4	4 3			A ← M ← A	0	0	1	1	R	0
	ANDB	C4	2 2	D4	3 2	E4	5 2	F4	4 3			B ← M ← B	0	0	1	1	R	0
Bit Test	BITA	85	2 2	95	3 2	A5	5 2	B5	4 3			A ← M	0	0	1	1	R	0
	BITB	C5	2 2	D5	3 2	E5	5 2	F5	4 3			B ← M	0	0	1	1	R	0
Clear	CLR					6F	7 2	7F	6 3			00 ← M	0	0	R	S	R	R
	CLRA							4F	2 1			00 ← A	0	0	R	S	R	R
	CLRB							5F	2 1			00 ← B	0	0	R	S	R	R
Compare	CMPA	81	2 2	91	3 2	A1	5 2	B1	4 3			A ← M	0	0	1	1	1	1
	CMPB	C1	2 2	D1	3 2	E1	5 2	F1	4 3			B ← M	0	0	1	1	1	1
Compare Accum	CBA							11	2 1			A ← B	0	0	1	1	1	1
Complement, 1's	COM					63	7 2	73	6 3			M ← M	0	0	1	1	R	S
	COMA							43	2 1			A ← A	0	0	1	1	R	S
	COMB							53	2 1			B ← B	0	0	1	1	R	S
Complement, 2's (Negate)	NEG					60	7 2	70	6 3			00 ← M ← M	0	0	2	1	2	2
	NEGA							40	2 1			00 ← A ← A	0	0	2	1	2	2
	NEGB							50	2 1			00 ← B ← B	0	0	2	1	2	2
Decimal Adjust, A	DAA							19	2 1			Converts Binary Add. of BCD Characters into BCD Format	0	0	2	1	3	3
Decrement	DEC					6A	7 2	7A	6 3			M ← M - 1	0	0	1	1	4	4
	DECA							4A	2 1			A ← A - 1	0	0	1	1	4	4
	DECB							5A	2 1			B ← B - 1	0	0	1	1	4	4
Exclusive OR	EORA	88	2 2	98	3 2	A8	5 2	B8	4 3			A ← M ← A	0	0	1	1	R	0
	EORB	C8	2 2	D8	3 2	E8	5 2	F8	4 3			B ← M ← B	0	0	1	1	R	0
Increment	INC					6C	7 2	7C	6 3			M ← M + 1	0	0	1	1	5	5
	INCA							4C	2 1			A ← A + 1	0	0	1	1	5	5
	INCB							5C	2 1			B ← B + 1	0	0	1	1	5	5
Load Accum	LQAA	86	2 2	96	3 2	A6	5 2	B6	4 3			M ← A	0	0	1	1	R	0
	LQAB	C6	2 2	D6	3 2	E6	5 2	F6	4 3			M ← B	0	0	1	1	R	0
Or, Inclusive	ORAA	8A	2 2	9A	3 2	AA	5 2	BA	4 3			A ← M ← A	0	0	1	1	R	0
	ORAB	CA	2 2	DA	3 2	EA	5 2	FA	4 3			B ← M ← B	0	0	1	1	R	0
Push Data	PSHA							36	4 1			A ← Msp, SP - 1 ← SP	0	0	1	1	R	0
	PSHB							37	4 1			B ← Msp, SP - 1 ← SP	0	0	1	1	R	0
Pull Data	PULA							32	4 1			SP + 1 ← SP, Msp ← A	0	0	1	1	R	0
	PULB							33	4 1			SP + 1 ← SP, Msp ← B	0	0	1	1	R	0
Rotate Left	ROL					68	7 2	78	6 3			M	0	0	1	1	6	6
	ROLA							48	2 1			A	0	0	1	1	6	6
	ROLB							58	2 1			B	0	0	1	1	6	6
Rotate Right	ROR					69	7 2	79	6 3			M	0	0	1	1	7	7
	RORA							49	2 1			A	0	0	1	1	7	7
	RORB							59	2 1			B	0	0	1	1	7	7
Shift Left, Arithmetic	ASL					60	7 2	70	6 3			M	0	0	1	1	8	8
	ASLA							40	2 1			A	0	0	1	1	8	8
	ASLB							50	2 1			B	0	0	1	1	8	8
Shift Right, Arithmetic	ASR					61	7 2	71	6 3			M	0	0	1	1	9	9
	ASRA							41	2 1			A	0	0	1	1	9	9
	ASRB							51	2 1			B	0	0	1	1	9	9
Shift Right, Logic	LSR					64	7 2	74	6 3			M	0	0	1	1	10	10
	LSRA							44	2 1			A	0	0	1	1	10	10
	LSRB							54	2 1			B	0	0	1	1	10	10
Store Accum	STAA			97	4 2	A7	6 2	B7	5 3			A ← M	0	0	1	1	R	0
	STAB			D7	4 2	E7	6 2	F7	5 3			B ← M	0	0	1	1	R	0
Subtract	SUBA	80	2 2	90	3 2	A0	5 2	B0	4 3			A ← M ← A	0	0	1	1	1	1
	SUBB	C0	2 2	D0	3 2	E0	5 2	F0	4 3			B ← M ← B	0	0	1	1	1	1
Subtract Accum	SBA							10	2 1			A ← B ← A	0	0	1	1	1	1
Subtr. with Carry	SBCA	82	2 2	92	3 2	A2	5 2	B2	4 3			A ← M ← C ← A	0	0	1	1	1	1
	SBCB	C2	2 2	D2	3 2	E2	5 2	F2	4 3			B ← M ← C ← B	0	0	1	1	1	1
Transfer Accum	TAB							16	2 1			A ← B	0	0	1	1	R	0
	TBA							17	2 1			B ← A	0	0	1	1	R	0
Test, Zero or Minus	TST					6D	7 2	7D	6 3			M ← 00	0	0	1	1	R	0
	TSTA							4D	2 1			A ← 00	0	0	1	1	R	0
	TSTB							5D	2 1			B ← 00	0	0	1	1	R	0

LEGEND:

OP Operation Code (Hexadecimal)  
~ Number of MPU Cycles  
n Number of Program Bytes  
+ Arithmetic Plus  
- Arithmetic Minus  
• Boolean AND  
Msp Contents of memory location pointed to by Stack Pointer

• Boolean Inclusive OR  
⊕ Boolean Exclusive OR  
■ Complement of M  
- Transfer Into  
0 Bit Zero  
00 Byte Zero

CONDITION CODE SYMBOLS:

M Half-carry from bit 2  
I Interrupt mask  
N Negative (sign bit)  
Z Zero (byte)  
V Overflow, 2's complement  
C Carry from bit 7  
R Reset Always  
S Set Always  
1 Test and set if true, cleared otherwise  
• Not Affected

Note: Accumulator addressing mode instructions are included in the column for IMPLIED addressing

Table A-II. Index Register and Stack Manipulation Instructions (MC 6800)

																	COND. CODE REG.					
		IMMED			DIRECT			INDEX			EXTND			IMPLIED			BOOLEAN/ARITHMETIC OPERATION					
POINTER OPERATIONS	MNEMONIC	OP	~	=	OP	~	=	OP	~	=	OP	~	=	OP	~	=	H	I	N	Z	V	C
Compare Index Reg	CPX	8C	3	3	9C	4	2	AC	6	2	BC	5	3									
Decrement Index Reg	DEX													09	4	1						
Decrement Stack Ptr	DES													34	4	1						
Increment Index Reg	INX													08	4	1						
Increment Stack Ptr	INS													31	4	1						
Load Index Reg	LOX	CE	3	3	DE	4	2	EE	6	2	FE	5	3									
Load Stack Ptr	LDS	8E	3	3	9E	4	2	AE	6	2	BE	5	3									
Store Index Reg	STX				DF	5	2	EF	7	2	FF	6	3									
Store Stack Ptr	STS				9F	5	2	AF	7	2	BF	6	3									
Index Reg → Stack Ptr	TXS													35	4	1						
Stack Ptr → Index Reg	TSX													30	4	1						
BOOLEAN/ARITHMETIC OPERATION																						
X <sub>H</sub> - M, X <sub>L</sub> - (M + 1)																						
X - 1 - X																						
SP - 1 - SP																						
X + 1 - X																						
SP + 1 - SP																						
M → X <sub>H</sub> , (M + 1) → X <sub>L</sub>																						
M → SP <sub>H</sub> , (M + 1) → SP <sub>L</sub>																						
X <sub>H</sub> → M, X <sub>L</sub> → (M + 1)																						
SP <sub>H</sub> → M, SP <sub>L</sub> → (M + 1)																						
X - 1 → SP																						
SP + 1 → X																						

Table A-III. Jump and Branch Instructions (MC 6800)

														CCND. CODE REG.						
OPERATIONS	MNEMONIC	RELATIVE			INDEX			EXTND			IMPLIED			BRANCH TEST						
		OP	~	=	OP	~	=	OP	~	=	OP	~	=	H	I	N	Z	V	C	
Branch Always	BRA	20	4	2										None	•	•	•	•	•	•
Branch If Carry Clear	BCC	24	4	2										C = 0	•	•	•	•	•	•
Branch If Carry Set	BCS	25	4	2										C = 1	•	•	•	•	•	•
Branch If = Zero	BEQ	27	4	2										Z = 1	•	•	•	•	•	•
Branch If > Zero	BGE	2C	4	2										$N \oplus V = 0$	•	•	•	•	•	•
Branch If > Zero	BGT	2E	4	2										$Z + (N \oplus V) = 0$	•	•	•	•	•	•
Branch If Higher	BHI	22	4	2										$C + Z = 0$	•	•	•	•	•	•
Branch If < Zero	BLE	2F	4	2										$Z + (N \oplus V) = 1$	•	•	•	•	•	•
Branch If Lower Or Same	BLS	23	4	2										$C + Z = 1$	•	•	•	•	•	•
Branch If < Zero	BLT	2D	4	2										$N \oplus V = 1$	•	•	•	•	•	•
Branch If Minus	BMI	28	4	2										N = 1	•	•	•	•	•	•
Branch If Not Equal Zero	BNE	26	4	2										Z = 0	•	•	•	•	•	•
Branch If Overflow Clear	BVC	28	4	2										V = 0	•	•	•	•	•	•
Branch If Overflow Set	BVS	29	4	2										V = 1	•	•	•	•	•	•
Branch If Plus	BPL	2A	4	2										N = 0	•	•	•	•	•	•
Branch To Subroutine	BSR	8D	8	2											•	•	•	•	•	•
Jump	JMP				GE	4	2	7E	3	3				See Special Operations	•	•	•	•	•	•
Jump To Subroutine	JSR				AD	8	2	8D	9	3						•	•	•	•	•
No Operation	NOP										01	2	1	Advances Prog. Cntr. Only	•	•	•	•	•	•
Return From Interrupt	RTI										3B	10	1			•	•	•	•	•
Return From Subroutine	RTS										39	5	1		•	•	•	•	•	•
Software Interrupt	SWI										3F	12	1	See Special Operations	•	•	•	•	•	•
Wait for Interrupt*	WAI										3E	9	1			•	•	•	•	•

\*WAI puts Address Bus, R/W, and Data Bus in the three state mode while VMA is held low.

MICROCOMPUTER BUS

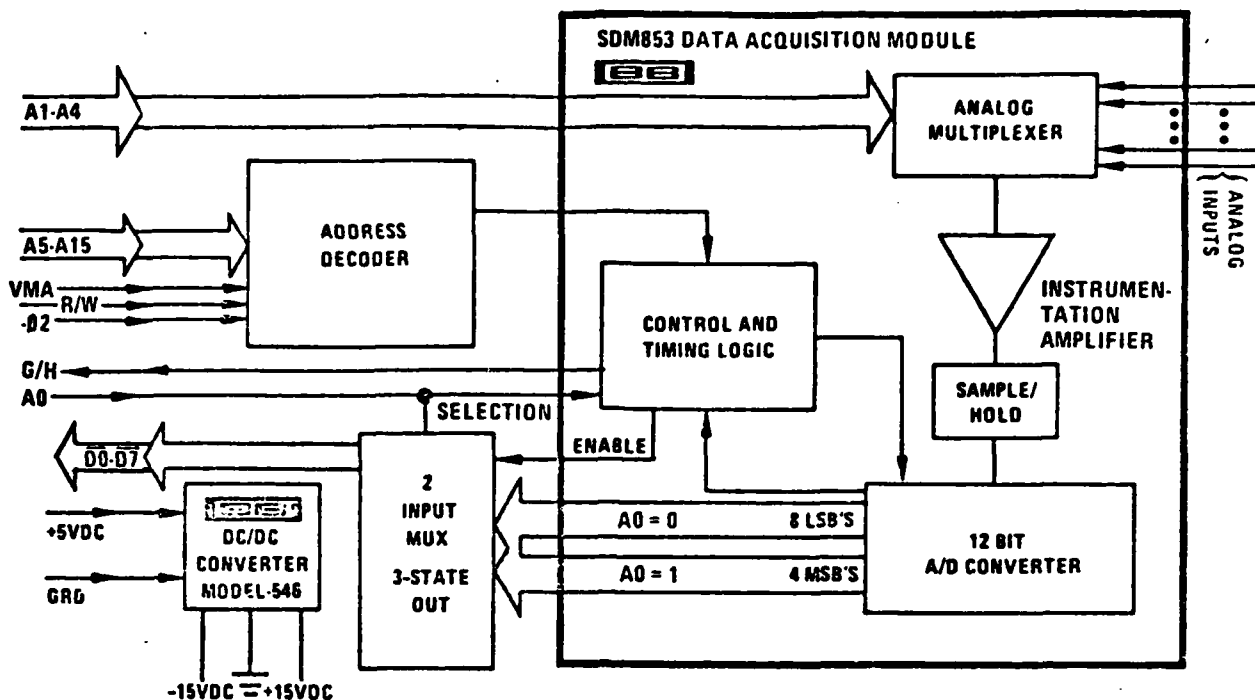


Figure A-3. Analog-to-Digital Converter - MP7208/7216

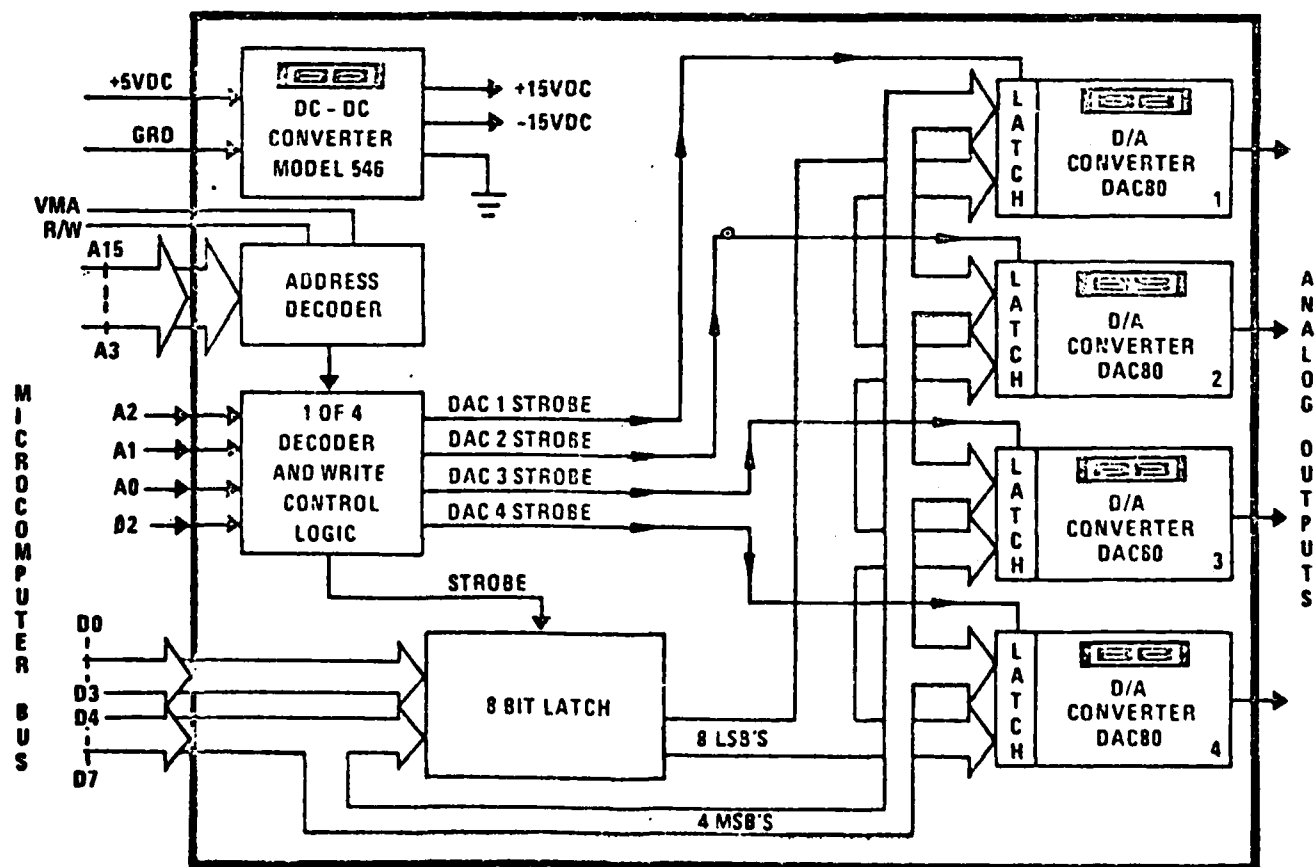


Figure A-4. Digital-to-Analog Converter - MP7104

TABLE A-IV

CONVERTER CHARACTERISTICS ANALOG TO DIGITAL

NUMBER OF CHANNELS	8
INPUT VOLTAGE	+ 10 MV TO + 10 V
INPUT IMPEDANCE	100 MEGOHMS
RESOLUTION	12 BITS BINARY
CONVERSION TIME (+ 10 V)	33 MICROSECONDS

DIGITAL TO ANALOG

NUMBER OF CHANNELS	4
OUTPUT VOLTAGE, VDC	+2.5, +5, +10, 0 TO 5, 0 TO 10
OUTPUT IMPEDANCE	1 OHM
RESOLUTION	12 BITS BINARY

- o Addition of a Gray-to-Binary code converter circuit board. A block diagram of this board appears in Figure A-5 and detailed component and interconnection information is provided in Figure A-6.
- o Addition of internal wiring to interconnect the electrical connector, Gray-to-Binary code converter, Peripheral Interface Adapter, and D/A converter.

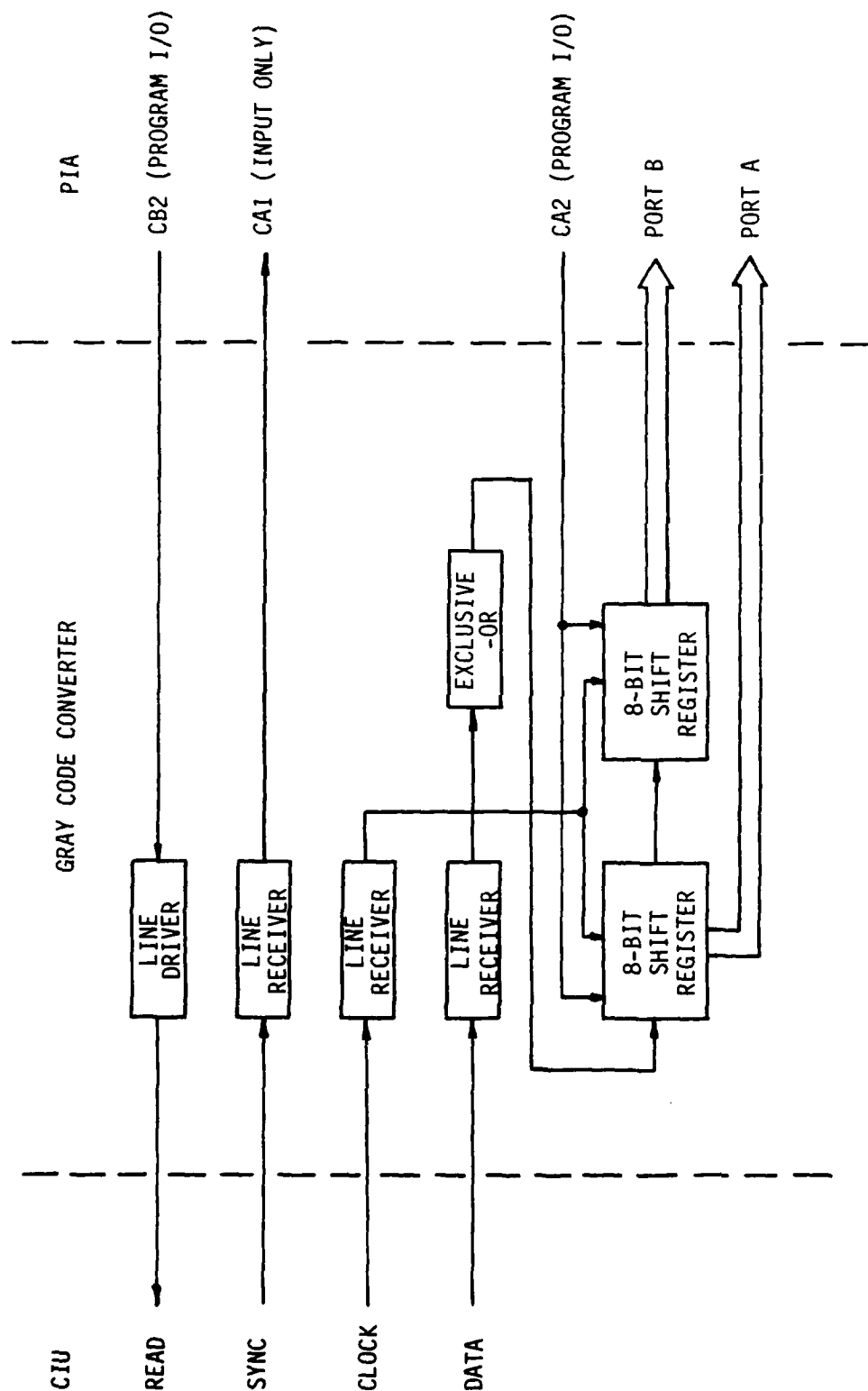


Figure A-5. Gray-to-Binary Code Converter, Block Diagram

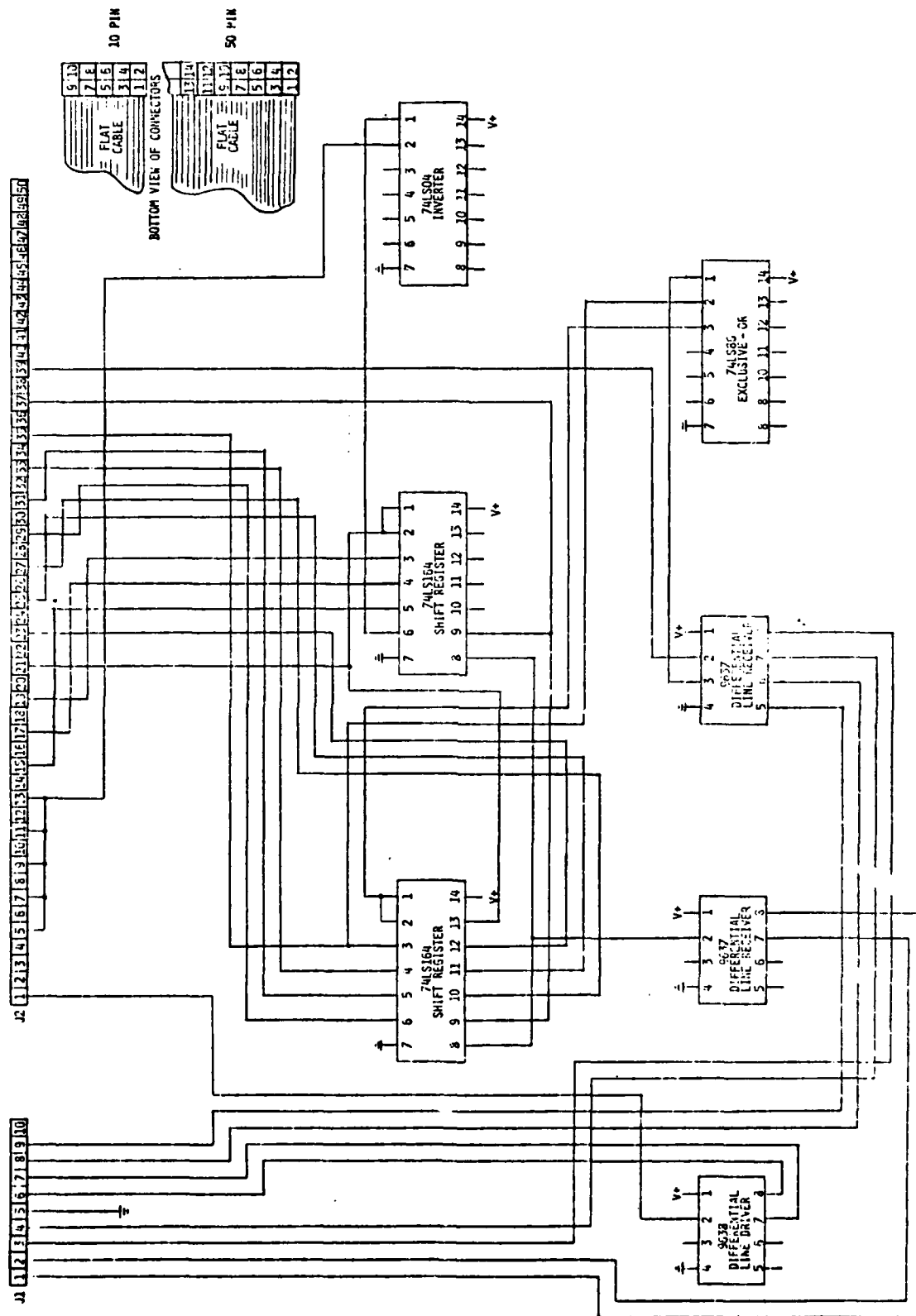


Figure A-6. Gray-To-Binary Converter, Interconnection Diagram

APPENDIX B

DIGITAL FLY-BY-LIGHT AFCAS/LODT  
FLIGHT PROGRAM SOFTWARE

INSTRUCTION		EXECUTION TIME	COMMENTS
LOCATION	OP. CODE		
00 50			CMD1
00 52			POST
00 54			CMD2
00 56			POS2
00 58			ERROR
00 5A			CARRY
00 5C			LOADING SWITCH
00 5E			MONITOR CONTROL
00 60			CMD CTR
00 62			POS CTR
00 64			ERROR CTR
00 66			XX, PLUS ON TIME; YY, MINUS ON TIME
	XX XX		
	XX XX		
	XX XX		
	XX XX		
	XX XX		
	XX --		
	XX --		
	XX --		
	XX --		
	XX --		
	XX XX		
	XX YY		

INSTRUCTION			EXECUTION TIME	COMMENTS
LOCATION	OP. CODE	OPERANDS		
CC 55	CE	04 00		LDX #
CC 58	FF	EF 06		STX
CC 5B	OF	-- --		SEI
CC 5C	86	34 --		LDAA #
CC 5E	B7	84 01		STAA
CC 61	86	3C --		LDAA #
CC 63	B7	84 01		STAA
CC 66	B7	84 03		STAA
CC 69	86	1F --		LDAA #
CC 6B	97	60 --		STAA
CC 6D	97	62 --		STAA
CC 6F	CE	04 00		LDX #
CC 72	DF	64 --		STX
CC 74	86	81 --		LDAA #
CC 76	97	5C --		STAA
CC 78	86	1A --		LDAA #
CC 7A	4A	-- --		DECA
CC 7B	26	FD --		BNE D1
CC 7D	86	34 --		LDAA #
CC 7F	B7	84 03		STAA
CC 82	86	EC 00		LDAA
CC 85	01	-- --		NOP
CC 86	FE	EC 00		LDX
CC 89	DF	50 --		STX
CC 8B	B6	84 01		LDAA
CC 8E	2A	FB --		BPL WAIT
				LOAD 5 VOLTS
				TURN ON DAC-4 (RELAY)
				CLEAR SHIFT REGISTERS
				SET CLEAR HIGH ON SHIFT REGISTERS (CA2)
				SET READ PULSE (CB2)
				INITIALIZE COMMAND COUNTER
				INITIALIZE POSITION COUNTER
				INITIALIZE ERROR COUNTER
				SET LOADING SWITCH
				DELAY FOR READ PULSE
				SET READ PULSE LOW
				START A/D FOR COMMAND
				STORE COMMAND VALVE
				BRANCH IF NO DATA

DATE

SUBROUTINE - INPUT 1

PROGRAM - DFBL (OPTIC SENSOR)

LOCATION	INSTRUCTION		EXECUTION TIME	COMMENTS
	OP. CODE	OPERANDS		
CC 90	CE	07 FF	3/ 3	LDX #
CC 93	FF	EF 00	6/ 9	STX
CC 96	FF	EF 02	6/ 15	STX
CC 99	96	5C --	3/ 18	LDAA
CC 98	2B	16 --	4/ 22	BMI CHECK
CC 9D	B6	EC 00	4/ 26	LDAA
CC A0	01	-- --	2/ 61	NOP
CC A1	FE	EC 00	5/ 66	LDX
CC A4	DF	50 --	5/ 71	STX
CC A6	86	81 --	2/ 73	LDAA #
CC A8	97	5C --	4/ 77	STAA
CC AA	86	04 --	2/ 79	LDAA #
CC AC	4A	-- --	2/ 81	DECA
CC AD	2A	FD --	4/ 109	BPL D2
CC AF	01	-- --	2/ 111	NOP
CC B0	7E	CC E7	3/ 114	JMP CMD1
CC B3	B6	84 01	4/ 26	LDAA
CC B6	2B	03 --	4/ 30	BMI READY
CC B8	7E	CE A1		JMP RELAY
CC BB	F6	84 02	4/ 34	LDAB
CC BE	01	-- --	2/ 36	NOP
CC BF	D7	52 --	4/ 40	STAB
CC C1	B6	84 00	4/ 44	LDAA
CC C4	01	-- --	2/ 4	NOP
CC C5	97	53 --	4/ 50	STAA
CC C7	DE	52 --	4/ 54	LDX
CC C9	FF	EF 04	6/ 60	STX
CC CC	57	-- --	2/ 62	ASRB
				LOAD WITH 10 VOLTS
				DAC-1
				DAC-2
				READ LOADING SWITCH
				BRANCH IF SWITCH SET
				START A/D CONVERSION FOR COMMAND
				LOAD COMMAND 1
				STORE COMMAND 1
				SET INPUT SWITCH
				DELAY LOOP FOR LOST TIME
				JUMP TO COMMAND LIMITS 1
				BRANCH IF DATA READY
				TURN OFF RELAY
				LOAD MSB OF POSITION
				STORE MSB OF POSITION (FOR READOUT)
				LOAD LSB OF POSITION
				STORE LSB OF POSITION (FOR READOUT)
				LOAD POSITION (FOR READOUT)
				OUTPUT DATA TO INSTRUMENT
				SHIFT MSB OF POSITION

AD-A132 638

FLIGHT EVALUATION OF A LINEAR OPTICAL DISPLACEMENT  
TRANSDUCER(U) ROCKWELL INTERNATIONAL COLUMBUS OH NORTH  
AMERICAN AIRCRAFT OP.. E J SOLOMON MAY 83 NR83H-20  
NAC-TR-2329 N00163-82-C-0232

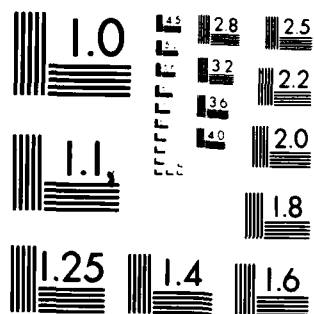
2/2

UNCLASSIFIED

F/G 1/4

NL


END  
DATE  
FILMED  
10-83  
DTIC



MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS 1963-A

DATE

SUBROUTINE - INPUT 1 (CONT'D)

PROGRAM - DFBL (OPTIC SENSOR)

INSTRUCTION			EXECUTION TIME	COMMENTS
LOCATION	OP. CODE	OPERANDS		
CC CD	46	-- --	2/ 64	ROR A
CC CE	D7	52 --	4/ 68	STAB
CC D0	97	53 --	4/ 72	STAA
CC D2	C6	34 --	2/ 74	LDAB #
CC D4	F7	84 01	5/ 79	STAB
CC D7	C6	3C --	2/ 81	LDAB #
CC D9	F7	84 01	5/ 86	STAB
CC DC	F7	84 03	5/ 91	STAB
CC DF	7F	00 5C	6/ 97	CLR
CC E2	86	03 --	2/ 99	LDAA #
CC E4	4A	-- --	2/ 101	DECA
CC E5	2A	FD --	4/ 117	BNE D3
				ROTATE LSB POSITION (+10V - +5V)
				STORE MSB OF POSITION
				STORE LSB OF POSITION
				CLEAR SHIFT REGISTERS
				SET CLEAR ON SHIFT REGISTERS
				SET READ PULSE
				RESET LOADING SWITCH
				DELAY FOR LOST TIME

DATE

SUBROUTINE - CMD 1 LIMITS

PROGRAM - DFBL (OPTIC SENSOR)

INSTRUCTION		EXECUTION TIME	COMMENTS
LOCATION	OP. CODE		
CC E7	96	50 --	LDA A
CC E9	2B	08 --	BMI
CC EB	81	04 --	CMP
CC ED	2B	13 --	BMI
CC EF	CE	04 00	LDX
CC F2	DF	50 --	STX
CC F4	20	12 --	BRA
CC F6	40	-- --	NEG
CC F7	81	05 --	CMP
CC F9	2B	07 --	BMI
CC FB	CE	FC 00	LDX
CC FE	DF	50 --	STX
CD 00	20	06 --	BRA
CD 02	73	00 00	COM
CD 05	73	00 00	COM
CD 08	73	00 00	COM
CD 0B	01	-- --	POP
		3/ 120	LOAD COMMAND 1
		4/ 124	BRANCH ON MINUS TO F6
		2/ 126	
		4/ 130	BRANCH ON MINUS TO 02
		3/ 133	LOAD +5V
		5/ 138	
		4/ 142	BRANCH TO 08
		2/ 126	
		2/ 128	
		4/ 132	BRANCH ON MINUS TO 02
		3/ 135	LOAD -5V
		5/ 140	
		4/ 144	BRANCH TO 08
		6/ 136	
		6/ 142	
		6/ 150	
		2/ 152	

## PROGRAM - DFBL (OPTIC SENSOR)

## SUBROUTINE - ERROR

DATE

INSTRUCTION			EXECUTION TIME	COMMENTS
LOCATION	OP. CODE	OPERANDS		
CC 0C	96	53 --	3/ 3	LDA-A POSITION (L.S. BYTE)
CD 0E	43	-- --	2/ 5	COM-A
CD 0F	98	51 --	3/ 8	ADD LS = CMD - POS
CD 11	24	04 --	4/ 12	BCC
CD 13	C6	01 --	2/ 14	LDA-B 01
CD 15	20	03 --	4/ 18	BRA
CD 17	01	-- --	2/ 14	NOP
CD 18	01	-- --	2/ 16	NOP
CD 19	5F	-- --	2/ 18	CLR-B
CD 1A	D7	5A --	4/ 22	STA-B
CD 1C	D6	52 --	3/ 25	LDA-B
CD 1E	53	-- --	2/ 27	COM-B
CD 1F	DB	50 --	3/ 30	ADD-B
CD 21	DB	5A --	3/ 33	ADD-B
CD 23	57	-- --	2/ 35	ASR-B
CD 24	46	-- --	2/ 37	ROR-A
CE 25	57	-- --	2/ 39	ASR-B
CD 26	46	-- --	2/ 41	ROR-A
CD 27	D7	58 --	4/ 45	STA-B
CD 29	97	59 --	4/ 49	STA-A
CD 2B	01	-- --	2/ 51	NOP

DATE

## SUBROUTINE - GAIN CONTROL

## PROGRAM - DFBL (OPTIC SENSOR)

INSTRUCTION		EXECUTION TIME	COMMENTS
LOCATION	OP. CODE		
CD 2C	D6	3/ 48	LDA-B ERROR, LO
CD 2E	96	3/ 51	LDA-A ERROR, HI
CD 30	01	2/ 53	NOP
CD 31	01	2/ 55	NOP
CD 32	4D	2/ 57	TST-A
CD 33	28	4/ 61	BMI
			TO NEG ERROR

## PROGRAM - DFBL (OPTIC SENSOR)

## SUBROUTINE - POSITIVE ERROR

DATE

INSTRUCTION			EXECUTION TIME	COMMENTS
LOCATION	OP. CODE	OPERANDS		
CD 35	84	07 --	2/ 63	AND-A
CD 37	26	0F --	4/ 67	BNE
CD 39	C4	80 --	2/ 69	AND-B
CD 38	26	0E	4/ 73	BNE
CD 30	D6	59 --	3/ 76	LDA-B
CD 3F	D7	66 --	4/ 80	STA-B
CD 41	86	7F --	2/ 82	LDA-A
CD 43	10	-- --	2/ 84	SBA
CD 44	97	67 --	4/ 88	STA-A
CD 46	20	34 --	4/ 92	BRA
CD 48	01	01 01	6/ 73	NOP
CD 48	86	7F --	2/ 75	LDA-A
CD 4D	97	66 --	4/ 79	STA-A
CD 4F	C6	00 --	2/ 81	LDA-B
CD 51	D7	67 --	4/ 85	STA-B
CD 53	01	-- --	2/ 87	NOP
CD 54	20	26 --	4/ 91	BRA
				TO SET MAX MODULATION TIME
				TO SET MAX MOD. TIME
				ERROR, LO
				TIME FOR POS. MOD.
				7F
				TIME FOR NEG. MOD.
				TO POS. OUTPUT
				7F
				TIME FOR POS. MOD.
				00
				TIME FOR NEG. MOD.
				TO POS. OUTPUT

INSTRUCTION		EXECUTION TIME	COMMENTS
LOCATION	OP. CODE		
CD 56	43	2/ 63	COM-A
CD 57	84	2/ 65	AND
CD 59	26	4/ 69	BNE
CD 58	53	2/ 71	COM-B
CD 5C	C4	2/ 73	AND
CD 5E	26	4/ 77	BNE
CD 60	D6	3/ 80	LDA-B
CD 62	53	2/ 82	COM-B
CD 63	D7	4/ 86	STA-B
CD 65	86	2/ 88	LDA-A
CD 67	10	2/ 90	SBA
CD 68	97	4/ 94	STA-A
CD 6A	20	4/ 98	BRA
CD 6C	01	4/ 73	NOP
CD 6E	01	4/ 77	NOP
CD 70	86	2/ 79	LDA-A
CD 72	97	4/ 83	STA-A
CD 74	C6	2/ 85	LDA-B
CD 76	D7	4/ 89	STA-B
CD 78	01	4/ 93	NOP
CD 7A	20	4/ 97	BRA
			TO SET MAX NEG. MOD. TIME
			TO SET MAX NEG. MOD. TIME
			ERROR, LO
			TIME FOR NEG. MOD. TIME
			7F
			TIME FOR POS. MOD. TIME
			TO NEG. OUTPUT
			7F
			TIME FOR NEG. MOD.
			00
			TIME FOR POS. MOD.
			TO NEG. OUTPUT

DATE

SUBROUTINE - PLUS OUTPUT

PROGRAM - DFBL (OPTIC SENSOR)

INSTRUCTION			EXECUTION TIME	COMMENTS
LOCATION	OP. CODE	OPERANDS		
CD 7C	86	7F --	2/ 2	LDA-A
CD 7E	4A	-- --	2/ 4	DEC-A
CD 7F	2A	FD --	4/ 774	BPL
CD 81	96	66 --	2/ 776	LDA-A
CD 83	4A	-- --	2/	DEC-A
CD 84	2A	FD --	4/ 782*	BPL
CD 86	CE	F8 00	3/ 785	LDX
CE 89	FF	EF 00	6/ 791	STX
CD 8C	FF	EF 02	6/ 797	STX
CD 8F	96	67 --	2/ 799	LDA-A
CD 91	4A	-- --	2/	DEC-A
CD 92	2A	FD --	4/1567*	BPL
CD 94	20	1A --	4/1571	BRA
			PLUS ON TIME	
			-10V	
			DAC-1	
			DAC-2	
			MINUS ON TIME	
			TO MONITOR	
			*TIME WITH ZERO ERROR	

DATE

SUBROUTINE - MINUS OUTPUT

PROGRAM - DFBL (OPTIC SENSOR)

INSTRUCTION		EXECUTION TIME	COMMENTS
LOCATION	OP. CODE		
CD 96	96	2/ 2	LDA-A
CD 98	D6	2/ 4	LDA-B
CD 9A	4A	2/	DEC-A
CD 9B	2A	4/ 774*	BPL
CD 9D	CE	3/ 777	LDX
CD A0	FF	6/ 783	STX
CD A3	FF	6/ 789	STX
CD A6	5A	2/	DEC-B
CD A7	2A	4/ 795*	BPL
CD A9	86	2/ 797	LDA-A
CD AB	4A	2/	DEC-A
CD AC	2A	4/1566*	BPL
CD AE	01	4/1570	NOP
			TIME FOR PLUS OUTPUT TIME FOR MINUS OUTPUT
			-10V DAC-1 DAC-2
			*TIME WITH ZERO ERROR

DATE

SUBROUTINE - INPUT 2

PROGRAM - DFBL (OPTIC SENSOR)

INSTRUCTION			EXECUTION TIME	COMMENTS
LOCATION	OP. CODE	OPERANDS		
CD B0	B6	EC 02	4/ 4	LDA-A
CD B3	01	-- --	2/ 37*	NOP
CD B4	FE	EC 02	5/ 42	LDX
CD B7	DF	54 --	5/ 47	STX
CD B9	B6	EC 06	4/ 51	LDA-A
CD BC	01	-- --	2/ 86*	NOP
CD BD	FE	EC 06	5/ 91	LDX
CD C0	DF	56 --	5/ 96	STX
CD C2	96	54 --	3/ 99	LDA-A
CD C4	2B	08 --	4/ 103	BMI
CD C6	81	04 --	2/ 105	CMP
CD C8	2B	13 --	4/ 109	BMI
CD CA	CE	04 00	3/ 112	LDX
CD CD	DF	54 --	4/ 117	STX
CD CF	20	12 --	4/ 121	BRA
CD D1	40	-- --	2/ 105	NEG
CD D2	81	05 --	2/ 107	CMP
CD D4	2B	07 --	4/ 111	BMI
CD D6	CE	FC 00	3/ 114	LDX
CD D9	DF	54 --	5/ 119	STX
CD DB	20	06 --	4/ 123	BRA
CD DD	73	00 00	6/ 117	COM
CD E0	73	00 00	6/ 123	COM
CD E3	73	00 00	6/ 129	COM
CD E6	96	5E --	3/ 132	LDA-A
CD E8	2A	16 --	4/ 136	BPL
CE EA	20	54 --	4/ 140	BRA
				START A-D CH. 1 CMD-2
				CMD-2
				START A-D CH. 3 POS-2
				POS-2
				CMD-2
				TO TEST NEG. LIMITS
				TEST POS. LIMITS
				+5V
				CMD-2
				TO EXIT
				TEST NEG. LIMITS
				-5V
				CMD-2
				MONITOR CONTROL
				TO CMD MONITOR
				TO POS. MONITOR

DATE

SUBROUTINE - CMD MONITOR

PROGRAM - DFBL (OPTIC SENSOR)

INSTRUCTION		EXECUTION TIME	COMMENTS
LOCATION	OP. CODE		
CE 00	96	3/ 3	LDA-A
CE 02	43	2/ 5	COM-A
CE 03	98	3/ 8	ADD
CE 05	24	4/ 12	BCC
CE 07	C6	2/ 14	LDA-B
CE 09	20	4/ 18	BRA
CE 08	01	4/ 16	NOP
CE 00	5F	2/ 18	CLR-B
CE 0E	D7	4/ 22	STA-B
CE 10	D6	3/ 25	LDA-B
CE 12	53	2/ 27	COM-B
CE 13	DB	3/ 30	ADD-B
CE 15	DB	3/ 33	ADD-B
CE 17	2A	4/ 37	BPL
CE 19	53	2/ 39	COM-B
CE 1A	C4	2/ 41	AND-B
CE 1C	26	4/ 45	BNE
CE 1E	86	2/ 47	LDA-A
CE 20	97	4/ 51	STA-A
CE 22	20	4/ 55	BRA
CE 24	7A	6/ 51	DEC
CE 27	2A	4/ 55	BPL
CE 29	20	4/ 57	BRA
CE 2B	86	2/ 57	LDA-A
CE 2D	97	4/ 61	STA-A
CE 2F	20	4/ 65	BRA
			CMD-1 (LO)
			CMD-2 (LO)
			01
			SAVE CARRY
			CMD-1 (HI)
			CMD-2 (HI)
			CARRY
			TO DEC CMD CTR
			RESET CMD CTR
			TO ERROR MONITOR
			CMD CTR
			TO ERROR MONITOR
			TO TURN OFF RELAY
			-1
			MONITOR CONTROL
			TO ERROR MONITOR

## PROGRAM - DFBL (OPTIC SENSOR)

## SUBROUTINE - POS MONITOR

DATE

INSTRUCTION			EXECUTION TIME	COMMENTS
LOCATION	OP. CODE	OPERANDS		
CE 40	96	53 --	3/ 3	LDA-A
CE 42	43	-- --	2/ 5	COM-A
CE 43	98	57 --	3/ 8	ADD
CE 45	24	04 --	4/ 12	BCC
CE 47	C6	01 --	2/ 14	LDA-B
CE 49	20	03 --	4/ 18	BRA
CE 4B	01	01 --	4/ 16	NOP
CE 4D	5F	-- --	2/ 18	CLR-B
CE 4E	D7	5A --	4/ 22	STA-B
CE 50	D6	52 --	3/ 25	LDA-B
CE 52	53	-- --	2/ 27	COM-B
CE 53	DB	56 --	3/ 30	ADD-B
CE 55	DB	5A --	3/ 33	ADD-B
CE 57	2A	01 --	4/ 37	BPL
CE 59	53	-- --	2/ 39	COM-B
CE 5A	C4	07 --	2/ 41	AND-B
CE 5C	26	06 --	4/ 45	BND
CE 5E	86	1F --	2/ 47	LDA-A
CE 60	97	62 --	4/ 51	STA-A
CE 62	20	07 --	4/ 55	BRA
CE 64	7A	00 62	6/ 51	DEC
CE 67	2A	02 --	4/ 55	BPL
CE 69	20	36 --	4/ 57	BRA
CE 6B	86	08 --	2/ 57	LDA-A
CE 6D	97	5E --	4/ 61	STA-A
CE 6F	20	0A --	4/ 65	BRA
				POS1 (LO)
				POS2 (LO)
				01
				SAVE CARRY
				POS1 (HI)
				POS2 (HI)
				CARRY
				TO DEC POS CTR
				RESET POS CTR
				TO ERROR MONITOR
				POS CTR
				TO ERROR MONITOR
				TO TURN OFF RELAY
				+08
				MONITOR CONTROL
				TO ERROR MONITOR

DATE

SUBROUTINE - MONITOR ERROR

PROGRAM - DFBL (OPTIC SENSOR)

LOCATION	INSTRUCTION		EXECUTION TIME	COMMENTS
	OP. CODE	OPERANDS		
CE 7B	86	34 --	2/ 2	LDA
CE 7D	B7	84 03	5/ 7	STAA
CE 80	96	58 --	3/ 10	LDA-A
CE 82	2A	04 --	4/ 14	BPL
CE 84	96	67 --	3/ 17	LDA-A
CE 86	20	04 --	4/ 21	BRA
CE 88	96	66 --	3/ 17	LDA-A
CE 8A	01	01 --	4/ 21	NOP
CE 8C	84	40 --	2/ 23	AND
CE 8E	27	09 --	4/ 27	BEQ
CE 90	DE	64 --	3/ 30	LDX
CE 92	09	-- --	4/ 34	DEX
CE 93	DF	64 --	4/ 38	STX
CE 95	26	07 --	4/ 42	BNE
CE 97	20	08 --	4/ 46	BRA
CE 99	CE	04 00	3/ 30	LDX
CE 9C	DF	64 --	5/ 35	STX
CE 9E	7E	CC 90	3/	JMP
CE A1	CE	00 00		LDX
CE A4	FF	EF 06		STX
CE A7	86	04 --		LDA
CE A9	CE	7F FF		LDX
CE AC	09	-- --		DEX
CE AD	26	FD --		BNE-3
CE AF	4A	-- --		DEC A
CE B0	26	F7 --		BNE-9
CE B2	7E	CC 55		JMP
				TO CEA9
				TO START
				TO PROG START
				TO TURN OFF RELAY
				1 SECOND
				TO PROG START
				OV
				TURN OFF RELAY
				4
				.25 SEC
				TO CEA9
				TO START

```

0000CE0400FFEF060FB604B76401860CB784
001001B72403861F97625762CE0400DF6456
002081975CE61A4A26FDE63457840326EC20
003001FEFC02DF50E584012AFBCEZ7FFFFEF
004022FFEF02565C2B16E6EC0001FEFC02DF
00505086E1975C6604A2AFD217ECCE7E654
0060012B037ECEA1F6842201D752B0E40001
00709753DE52FFEF045746L7525753C634F7
00808401C63CF70401F7B4237F205C20034A
00902AFD96502E0E81042B13CE2422DF5220
00A0124081052E07CEFC02DF502206730000
00B07300007300001650439E512404C601
00C0200301015FD75AD65253DE52DE5A5746
00D05746D758975901D659965201014C2B21
00E08407260FC480260ED659D766E67F1097
00F0672034010101867FF9766C620D7672120
010026432427261153C480E610D65953D767
0110867F109766202A01010101867F9767C6
012020D7660101201A867F4A2AFD56664A2A
0130FDCEFE020FFEF02FFEF025667412AF020
01401A9666D6674A2AFDCEFE020FFEF02FFEF
0150225A2AFD867F4A2AFDZ101B6EC0201FE
0160EC02DFS4B6EC0601FEFC06DF5096542B
01702B81042B13CE0400DF5420124081052B
018007CEFC02DF5420067300007320007300
019000965E2A1620540101010101010101
01A0210101010101010101010101010101
01B02404C601200301015FD75AD65053DE54
01C0DE5A2A2153C4072606861F976220077A
01D062602A0220765680975E204A01010101
01E0010101010101010101010101010101
01F02404C601200301015FD75AD65253DE56
0200DE5A2A0153C4072606861F976220077A
021000622AF220368638975E20CA01010101
0220010101010101010101010101010101
023067200496660101S4402709DE64C90DF64
024026072008CE0400DF647ECC90CE000FFF
0250EF068604CE7FFF0926FD4A26F77ECC55

```

Figure B-1. Digital Fly-By-Light PROM Map

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## APPENDIX C

### GENERAL TEST PLAN/PROCEDURES

FOR FLIGHT EVALUATION OF A

LINEAR OPTICAL DISPLACEMENT

TRANSDUCER

### GENERAL TEST PLAN/PROCEDURES

- I. TEST PLAN AND OBJECTIVES
- II. GROUND TEST PROCEDURE
- III. SYSTEM DESCRIPTION AND PILOT INFORMATION
- IV. FLIGHT TEST PROCEDURE
- V. FLIGHT INSTRUMENTATION

## I. TEST PLAN AND OBJECTIVES

This document describes the program test objectives, the aircraft ground test procedure, and the aircraft flight test procedure. It also contains descriptions of the system operation and the flight hardware. The prime objective of this program is to evaluate optical control of a direct drive actuator. This program uses a specially designed optical feedback sensor and an optical command system to control the direct drive rudder actuator of a T-2 aircraft. Approximately three hours of flight testing will be accomplished at the Columbus, Ohio facility of Rockwell International.

This test program combines the assets from two Navy programs for a flight test demonstration. The actuator which was developed as part of the Navy's Advance Flight Control Actuation System (AFCAS) is combined with a Navy developed Linear Optical Displacement Transducer (LODT) to optically control the rudder in a Navy T-2 trainer aircraft. The AFCAS has been a joint undertaking by the Navy and Rockwell International Corporation for several years. Earlier portions of this development program have established that a direct-drive control valve and building block configured actuator can be readily integrated into a computer-operated control-by-wire system. The most recent test program demonstrated the use of an electro-optical command system from the computer to actuator electronics.

This program tests the operation of the rudder control system using a digital-optical feedback sensor in place of an analog-electrical sensor used on previous tests. (The system is described in more detail in Section III.)

The system will be assembled and operated in the laboratory to ensure proper system operation prior to aircraft installation. Following the laboratory tests, the system will be installed in the T-2C aircraft. After installation, system ground checkout will be performed, and instrumentation operation will be verified. The aircraft will then be ready for flight test.

The flight safety features used for the previous AFCAS flight program are retained for this program. The two main features are:

- (1) Limit rudder travel so that a safe landing can be made with a "hard-over" rudder.
- (2) A bypass valve which permits the rudder to trail if hydraulic power is lost or system is switched off.

In addition, the microcomputer will be self-monitored. In the event the computer detects a failure or the pilot turns off the fly-by-light system, the directional control will revert to the analog system. Additional discussion of these features is contained in Section III.

## II. GROUND TEST PROCEDURE

CAUTION: Stay clear of rudder during test. In this configuration the rudder is a hydraulic powered system. The rudder will move rapidly with full force.

### 1. FILL AND BLEED HYDRAULIC SYSTEM

A 3000 psi ground cart containing MIL-H-83282 fluid is required.

- Before reconnecting AFCAS actuator, temporarily connect rudder actuator pressure and return lines together. Hose and adapter fittings provided by Department 871.
- Attach ground cart pressure, fill, and suction lines to aircraft.
- Apply 85 psi at fill fitting.
- Bleed air from heat exchanger bleed port located at the upper left aft corner of heat exchanger.
- Bleed air at pump suction, pressure, and case drain ports.
- Disconnect ground cart.
- Reconnect pressure and return lines to rudder actuator.

### 2. SYSTEM CHECKOUT

#### 2.1 Hydraulic System

- Connect 28 VDC external ground power supply cart to aircraft. DO NOT TURN ON AT THIS TIME.
- Apply 25 psig air pressure to reservoir. Use nitrogen bottle with pressure regulators. (Furnished by Department 871.)

CAUTION: Operation of the 8000 psi motor-pump unit without engines running requires external reservoir pressurization. Apply nitrogen pressure through a capped tee located near the reservoir pressure regulator.

- Disconnect power plug from EDU Recept J4. Disconnect both connectors from the microcomputer Recepts J2 and J3. Connect plug to heat exchanger blower.
- Disconnect connector from microcomputer power supply.
- Apply 28 VDC to aircraft. Turn on #2 inverter. Heat exchanger blower should be running.

- Turn rudder hydraulic power switch "ON" in cockpit. Observe that pressure is 8000 psi on cockpit gage. Look for leaks (especially at actuator).
- Turn off rudder hydraulic power switch, #1 inverter and 28 VDC ground power supply.

## 2.2 Electrical Analog System

- Connect J4 on the EDU to the A/C harness. Connect J3 on the EDU to the AFCAS test box provided by Department 871.
- Turn on 28 VDC ground power supply. Verify DFBL switch is "OFF".
- Turn #1 inverter "ON", then turn rudder hydraulic power switch "ON". Motor/pump should be running and EDU should be powered.
- Operate rudder pedals. Assure that operation is satisfactory. Rapidly oscillate rudder a sufficient number of cycles (at least 25) to remove any trapped air within the rudder actuator. Note sensitivity and dead band.
- Apply full right and left pedals. Measure and record rudder deflection. Maximum right and left rudder should be  $12 \pm 1/2$  degrees. Determine that rudder return to  $0 \pm 3/4$  degrees with no pedal force.
- At the AFCAS test box, measure and record the voltages shown below with no rudder pedal command.

<u>Description</u>	<u>Required Voltage</u>
Actuator LVDT Output Voltage	$0 \pm 0.200$ VDC
Force Transducer Output Voltage	$0 \pm 0.250$ VDC
Valve Drive Output Voltage	$0 \pm 0.500$ VDC

### 2.3 Microcomputer and Power Supply

- Turn DFBL switch "ON". Observe that DFBL light is "ON".
- Operate rudder pedals. Assure that operation is satisfactory.
- Apply full right and left pedals. Measure and record rudder deflection. Maximum right and left rudder should be  $12 \pm 1/2$  degrees. Determine that rudder returns to  $0 \pm 3/4$  degree with no pedal force.
- Measure and record the voltages shown below with no rudder pedal command.

<u>Description</u>	<u>Required Voltage</u>
Valve Drive Output Voltage	$0 \pm 0.500$ VDC

### 3. MONITOR CHECKS

- Remove one of the two fiber optic lines between the microcomputer and the EDU (Electronic Drive Unit).
- System should continue to operate. However response should be slowed and large or repeated inputs could cause system to monitor off.
- Remove second optical input.
- System should monitor off. DFBL switch "OFF" and DFBL light is not illuminated.

NOTE: If system is extremely well nulled, system may not monitor off until slight pedal force is applied.

- Reconnect optical command lines.
- Reengage DFBL (DFBL switch to "ON").
- Turn rudder hydraulic power switch to "OFF".
- Verify that DFBL switch goes to "OFF" and DFBL light is not illuminated.
- Manually move the rudder surface and verify rudder free to go to trail position with hydraulic power switch off.

CAUTION: Be sure hydraulic power is off before attempting to move surface.

- Reengage rudder hydraulic power switch. Turn DFBL switch to "ON".
- Cycle rudder pedals to ensure correct operation.
- Turn rudder hydraulic power switch "OFF".
- Turn #1 inverter "OFF" and remove external ground power.

### III. SYSTEM DESCRIPTION AND PILOT INFORMATION

The system functions the same as the Digital Advanced Flight Control Actuation System except the digital command and feedback signals are transmitted optically instead of electrically. The command system is the same as the previous fly-by-light program. The actuator feedback has been changed by removing one of the LVDT feedback sensors and replaced with a Linear Optical Displacement Transducer (LODT). In the fly-by-light mode, the LODT supplies the feedback signal while the remaining LVDT is used as a system monitor as well as providing data for instrumentation. To the pilot, system operation should appear identical to the previous systems tested.

The Analog Back-Up (ABU) mode is still retained using the remaining LVDT for feedback. In the ABU mode of operation all optical equipment is removed from the control loop. The ABU performance, as seen by the pilot, should be unchanged from previous programs. The rudder system components are:

- Electrical Motor Drive Pump
- Rudder Actuator
- Electronic Drive Unit
- Digital Microcomputer
- Force Transducers
- Microcomputer Power Supply
- Linear Optical Displacement Transducer which consists of
  - o Sensor Unit
  - o Computer Interface Unit
  - o Fiber Optic Cable

The aircraft configuration is very similar to that used for previous rudder control system tests. The original mechanical cable system between the rudder pedals and the rudder has been modified to incorporate the control-by-wire system. The rudder is controlled by a direct drive hydraulic actuator. The rudder pedals operate a force transducer and therefore have very little displacement.

When the DFBL is selected "ON", the electrical signal from the force transducer is sent to the microcomputer. This signal is summed in the microcomputer with a feedback signal from an LODT mounted on the rudder actuator. The summed or error signal is converted to a digital PWM (Pulse Width Modulated) drive signal. The digital error signal is transmitted optically to the EDU which power amplifies and drives the torque motor on the rudder actuator. The torque motor drives the control valve on the actuator.

When the DFBL switch is "OFF", the force transducer command is transmitted directly to the EDU which powers the torque motor which in turn drives a control valve on the actuator. The EDU contains redundant circuitry which provides high immunity to system failures. This system is illustrated in the functional block diagram of Figure C-1. With the DFBL switch in "OFF", the digital computer and the optics are still operating but do not control the rudder. However, it is possible to obtain recorded data on the optical sensor performance with the DFBL switch "OFF".

The system with the LODT installed will operate the same as previous Digital AFCAS programs with the same backup modes and emergency procedures. These features are discussed in the following paragraphs.

The rudder actuator has a pressure operated by-pass valve which permits the rudder to trail if hydraulic power is lost. In the event of a "hard over" type failure, the pilot can cause the rudder to trail by turning the 8000 psi rudder hydraulic power system switch to "OFF".

The rudder trim system is unchanged. Trim response will be different, however, due to the change from a manual to a fully powered rudder. The yaw damper system has been disconnected.

Maximum rudder displacement is reduced from + 25 degrees to + 12 degrees. This reduction will permit the pilot to land safely with a "hard over" rudder, opposite engine out, and a three knot cross wind. The relationship between rudder displacement and pedal force is approximately 7 lb./deg. of rudder movement (+ 84 lb. for full travel).

Because of the additional load imposed on the 28 VDC generators, the motor/pump unit can be operated only when both engines are running. For this reason, the unit can only be turned "ON" with both engines operating.

Modifications in the cockpit area are as follows:

1. 8000 psi hydraulic pressure on the rudder actuator and electric power to the EDU and microcomputer can be shut off by means of a rudder hydraulic power switch located on the pilot's auxiliary instrumentation control panel (shroud).

NOTE: For total flight control boost shut-off, the above hydraulic power switch and the normal system boost shut-off switch must be moved to "OFF". The rudder will trail in this situation and cannot be operated.

2. Output from the 8000 psi pump is displayed on the upper right hand side of the pilot's instrument panel.

NOTE: The pressure displayed is in the pump discharge line and will fall to zero when the hydraulic power switch is at "OFF".

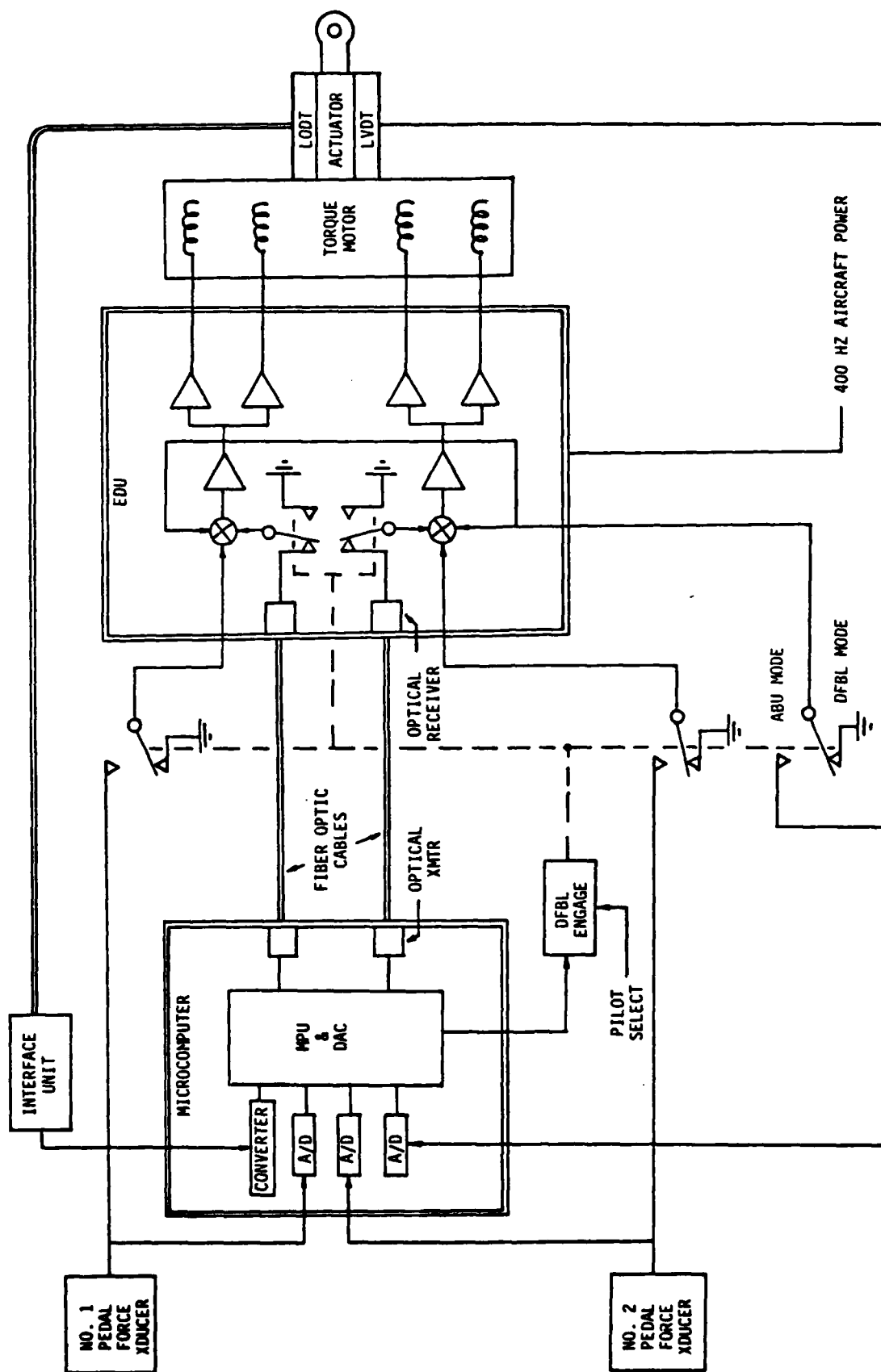


Figure C-1. DFBL/ABU Functional Block Diagram

3. An "oil hot" light has been provided on the pilot's auxiliary instrument panel (shroud). This light indicates excessive hydraulic system oil temperature. Actuation of the light is an indication of system malfunction.
4. The DFBL switch, located on the pilot's auxiliary instrumentation control panel, operates the microcomputer. When the computer is operating, the indicator light will be "ON". When the indicator light is not illuminated, the system will be operating in the analog backup mode.

Contingency procedures are:

1. DFBL Switch "ON", Hydraulic Power Switch "ON"
  - (a) If left and right yaw responses become significantly different or erratic, turn DFBL switch "OFF".
  - (b) If rudder becomes "hard over", turn DFBL switch "OFF".
  - (c) If still "hard over", turn hydraulic power switch "OFF".
2. DFBL Switch "OFF", Hydraulic Power Switch "ON"
  - (a) If the left and right yaw responses become significantly different for equal inputs, a malfunction in the system is indicated. Terminate test. Turn the rudder hydraulic power switch "OFF".
  - (b) If the rudder should become "hard over", terminate test. Turn rudder hydraulic power switch "OFF".
3. If the "oil hot" light comes on, terminate test. Turn rudder hydraulic power switch "OFF". Alternately cycle the speed brakes and landing gear during return flight to lower bulk fluid temperature. Stop cycle when fluid temperatures becomes normal.
4. If the 8000 psi system pressure drops below 6000 psi, terminate test. Turn the rudder hydraulic power switch "OFF".
5. If it should become necessary to shut-down one engine, turn the rudder hydraulic power switch "OFF" before engine shut-down.

NOTE: Shut-down of one engine will cause loss of 8000 psi hydraulic power.

#### IV. FLIGHT TEST PROCEDURE

##### 1. First Flight

GOAL - Functional check DFBL operation in flight, and to acquire flight time on the system.

MAXIMUM ALTITUDE - 20,000 feet

MAXIMUM SPEED - 250 KOAS

PILOT CHECKOUT - With engine operating and normal electrical power, turn hydraulic power switch "ON".

- Check rudder system by cycling pedals and observing normal rudder operation.
- Turn DFBL switch to "ON".
- Check rudder system by cycling pedals and observing normal rudder operation.
- Turn DFBL switch to "OFF".

TAKEOFF - First Flight T.O. in "ABU" mode (DFBL switch to "OFF").

PILOT MANEUVERS -

NOTE: Pilot to perform these at his discretion at safe altitude. Recorder "ON". Pilot to comment after landing. DFBL switch "ON".

- Apply small rudder inputs, note response and dead band.
- Apply pulse inputs, evaluate recentering, left and right.
- Make comparison of DFBL "feel" with ABU "feel".
- The pilot is encouraged to perform any additional maneuvers that would provide worthwhile data. Maneuvers that could result in dynamic overswing conditions are prohibited.
- Perform large side slip maneuvers left and right up to 1/2 directional control if possible.

LANDING - DFBL switch to remain "ON" for landing. Record data during landing if conditions permit.

POST FLIGHT -

- De-brief pilot after each flight. Pilot comments to be correlated with maneuvers and instrumentation correlator and markers.
- Copy of flight card with instrumentation correlation and pilot comments made available to Department 871.

- Copy of recorded data made available to Department 871.
- Make decisions regarding changes or additional procedure for next flight.

## 2. Second Flight

GOAL - Compare DFBL with analog AFCAS; acquire operational flight time on DFBL system.

MAXIMUM ALTITUDE - 20,000 feet

MAXIMUM SPEED - 250 knots

PILOT CHECKOUT - Same as flight one.

TAKEOFF - Turn DFBL switch to "ON"

PILOT MANEUVERS -

- Pilot to verify system operation with DFBL switch "ON".
- Place DFBL switch "OFF", verify directional control with analog system. (Slight trim changes may be present when switching, observe direction and magnitude of transient.)

NOTE: Pilot to perform these maneuvers with the DFBL switch alternately "ON" and "OFF" and to compare performance. Recorders "ON" for maneuvers.

Pilot to comment on performance.

- Apply small rudder inputs, note response and dead band.
- Apply pulse inputs, evaluate recentering, left and right.
- Make comparison of DFBL "feel" with ABU "feel".
- The pilot is encouraged to perform any additional maneuvers that would provide worthwhile data.

LANDING - Same as flight one.

POST FLIGHT - Same as flight one.

## 3. Third Flight (If Program Permits)

GOAL - Acquire additional flight time on DFBL control and obtain additional data points.

ALTITUDE - Sea Level to 30,000 feet

AIRSPEED - Up to 340 KOAS or 0.7 MN, whichever is less

PILOT CHECKOUT - Same as flight one.

TAKEOFF - Same as flight one.

PILOT MANEUVERS - Optional, dynamic overswing maneuvers are prohibited.

LANDING - Same as flight one.

POST FLIGHT - Same as flight one.

#### 4. Flight Conditions for Test

During the flight testing of the LODT it is desirable to operate at as many different flight conditions as possible. The relative priority of these flight conditions are given in Table C-I. Flights will be planned to obtain as many points per flight as possible while conforming to air traffic restrictions.

#### V. FLIGHT INSTRUMENTATION

The following charts contain a list of the instrumentation needed for flight testing of the LODT. There are three priority levels given for the instrumented data, (1) required to meet flight objective (2) highly desirable, and (3) nice to have but not necessary. Only two items fall in the required or mandatory class. They are the LVDT feedback and optical sensor signal. A special output will be provided from the microcomputer. They are labeled pigtails from connector J-6 of the microcomputer.

TABLE C-I

DESIRABLE FLIGHT CONDITIONS

150	1	1	2	3
200	2	1	1	3
250	2	2	2	3
300		3	3	
Above 300		3	3	
<hr/>				
	10K	15K	20K	30K

# PHOTO RECORDER SYSTEM

PARAMETER	RANGE	ACCURACY	READOUT RESPONSE
1. *Airspeed	50 to 500 kts (26 to 250 m/s)		
2. *Altitude	0 to 50,000 ft. (15.2 km)		
3. RPM, L/R Engines	0 to 8,000 RPM		
<u>AFCAS PARAMETERS</u>			
4. Temp, Fuselage Compartment Air	-50 to +350°F (-46 to +177°C)		2 Hz
5. Temp, Pump Suction Fluid	-50 to +350°F (-46 to +177°C)		2 Hz
6. *Temp, Pump Case Drain Fluid	-50 to +350°F (-46 to +177°C)	+3%	2 Hz
7. Temp, Heat Exchanger Inlet Fluid	-50 to +350°C (-46 to +177°C)		2 Hz
8. Temp, Heat Exchanger Outlet Fluid	-50 to +350°F (-46 to +177°C)		2 Hz
9. Temp Actuator	(-50 to 350°F)		

\*Desirable Parameter

# STRIP CHART RECORDER

PARAMETER	RANGE	ACCURACY	READOUT RESPONSE
1. Temp, Outside Air	-76 to +140°F (+60 C)		
2. Acceleration, Normal (Vertical)	-5 to +10g		
<u>AFCAS PARAMETERS</u>			
3. *Press, Pump Suction Line	0 to 50 psia (0 to .3MPa)		10 Hz
4. *Press, Pump Discharge Line	0 to 10,000 psig (0 to .6 Mpa)	+3% -3%	10 Hz
5. *Press, Pump Case Drain Line	0 to 100 psia (0 to .6 Mpa)	+3% -3%	10 Hz
6. Position, Rudder	+120°		10 Hz
7. **Position, AFCAS Transducer #1	+10 volts DC	+2% -2%	100 Hz
8. **LODT Output	+10 volts DC	+2% -2%	100 Hz
9. Force, AFCAS Transducer #1	+2.5 volts DC		10 Hz
10. Force, AFCAS Transducer #2	+2.5 volts DC		10 Hz
11. *Current, AFCAS Motor Coil #1	+1.0 volts DC	+2% -2%	10 Hz
12. *Current, AFCAS Motor Coil #2	+1.0 volts DC	+2% -2%	10 Hz
13. Current, AFCAS Motor Coil #3	+1.0 volts DC	+2% -2%	10 Hz
14. *Current, AFCAS Motor Coil #4	+1.0 volts DC	+2% -2%	10 Hz
15. **Temp, Oil Hot Light (+200 F)	Pilot Advisory		

\*Desirable Parameter

\*\*Mandatory Parameter

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### LIST OF ABBREVIATIONS/ACRONYMS

AC	Alternating Current
ABU	Analog Back-Up
ACIA	Asynchronous Interface Adapter
A/D	Analog to Digital
AFCAS	Advanced Flight Control Actuation System
Amp	Ampere
AROM	Alterable Read Only Memory
Aux	Auxiliary
°C	Degrees Celsius
cc/min	cubic centimeters per minute
c	centi ( $10^{-2}$ )
cm <sup>3</sup>	cubic centimeters
CIU	Computer Interface Unit
CMD	Pilot Command
CPU	Central Processing Unit
D/A	Digital to Analog
DAC	Digital to Analog Converter
db	decibel
DC	direct current
deg	degree
DFBL	Digital Fly-By-Light
DFBW	Digital Fly-By-Wire
DVM	Digital Voltmeter
EDU	Electronic Drive Unit

EPROM	Electrically Programmable Read Only Memory
°F	degrees Fahrenheit
FRP	Flight Reference Plane
FUS STA	fuselage station
ft	feet
F/O	Fiber Optics
F/T	force transducer
ft/sec	feet per second
gpm	gallons per minute
HOFCAS	Hydra-Optic Flight Control Actuation System
hp	horsepower
Hp	pressure altitude (29.91 in. Hg = Sea Level)
Hz	Hertz (cycles per second)
in.	inch
in <sup>2</sup>	square inches
in <sup>3</sup>	cubic inches
INST	instrument
I/O	input/output
k	kilo (10 <sup>3</sup> )
kg	kilogram
km	kilometer
KOAS	Knots Observed Airspeed (uncorrected)
kW	kilowatt
lb	pound
L	liter
LED	light emitting diode

L/m	liters per minute
LHS	Lightweight Hydraulic System
LODT	Linear Optical Displacement Transducer
LVDT	Linear Variable Differential Transformer
m	meter, also milli ( $10^3$ ), also minute
M	mega ( $10^6$ )
max	maximum
mm	Millimeter
M/N	model number
min	minute (time)
MPa	megapascals
MPU	Microprocessing Unit
m/s	meters per second
mv	millivolt
N	Newton (metric unit of force)
NAAO	North American Aircraft Operations
NAC	Naval Avionics Center
NADC	Naval Air Development Center
No.	Number
OAT	outside air temperature
P-P	peak-to-peak
P	differential pressure
Pa	pascal (metric unit of pressure)
pk to pk	peak to peak
PIA	Peripheral Interface Adapter

POS	rudder position
PROM	Programmable Read Only Memory
psi	pounds per square inch
psia	pounds per square inch absolute pressure
psig	pounds per square inch gauge pressure
PM	pulse modulation
P/N	part number
PWM	pulse width modulated
RAM	Random Access Memory
R&D	Research and Development
RH, R/H	right hand
ROM	Read Only Memory
rpm	revolutions per minute
s	second (time), also LaPlace transform operator
sec	second (time)
SL	sea level
TM	telemetry
T/O	take-off
UHF	ultra-high frequency
V	volt
VDC	volts direct current
W	watt
W.L.	water line
XDCR	transducer
XFMR	transformer

# SUMMARY OF METRIC CONVERSIONS

Area	in <sup>2</sup>	x	6.452	=	cm <sup>2</sup>
	ft <sup>2</sup>	x	.0929	=	m <sup>2</sup>
Fluid Flow	gal/min	x	3785	=	cc/min
	gal/min	x	3.785	=	L/min
	in <sup>3</sup> /sec	x	16.39	=	cc/sec
Force	lb	x	4.448	=	N
Length	in	x	2.540	=	cm
	ft	x	.3048	=	m
Mass	lb	x	.4536	=	kg
Pressure, Stress	psi	x	6895	=	Pa (=N/m <sup>2</sup> )
	psi	x	.06895	=	bar
Velocity, Speed	in/sec	x	2.540	=	cm/sec
	ft/sec	x	.3048	=	m/sec
	knots	x	.5144	=	m/sec
Volume	in <sup>3</sup>	x	16.39	=	cm <sup>3</sup> (-cc)
	gal	x	3.785	=	L
	l	x	1000	=	cm <sup>3</sup>
	m <sup>3</sup>	x	1000	=	L

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